Park Scientific Instruments

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USER'S MANUAL AND REFERENCE GUIDE FOR

STM-SA1
Scanning Tunneling Microscope

&

SFM-BD2
Scanning Force Microscope

February 1991

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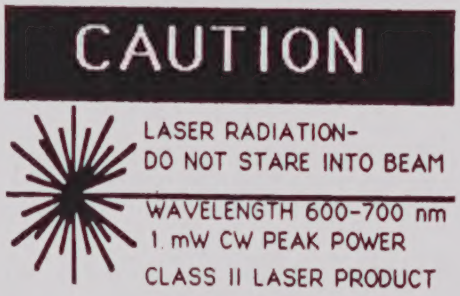
Laser Safety

The scanning force microscope SFM-BD2 contains a laser diode powered by a low voltage supply with maximum output of 1 mW CW in the wavelength range 600-700 nm. The system should always be operated with the scanner and sensor head covered as described in Chapter 4.

BEWARE OF HAZARDOUS ELECTROMAGNETIC AND LASER RADIATION. AVOID DIRECT EXPOSURE TO THE BEAM. STRICT OBSERVANCE OF THE FOLLOWING WARNING LABEL IS ADVISED:



Warning: Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous laser light exposure.

There are no user adjustments to the sensor head other than those described in the operation and maintenance section of this manual; refer all other technical matters to Park Scientific Instruments service personnel.

THIS PRODUCT COMPLIES WITH 21 CFR 1040.10 AND 1040.11.

How to Read this Manual

This manual presents the basic operational procedures for using the STM-SA1 and SFM-BD2 Microscope Systems as well as a reference guide to explain the individual components and their functions. You do not have to read all of it, but you do have to read part of it. Remember that PSI applications support engineers can help answer any questions you may have; do not hesitate to call us.

- If you are not familiar with STM and SFM, read Chapter 1 first.
- At the bare minimum read all the "Warning" and "Caution" boxes in order to prevent damage to your health and the instrument.
- The tutorial boxes are interspersed throughout the manual and are useful for a first time through. This is recommended for everyone.
- The boxed sections that open up with bold-face text give hints on how to greatly improve your images. You may get reasonable images without realizing you could have been getting much better ones. Therefore, read all these boxes.
- Read the main text as needed. A bold-face statement beginning a paragraph can tell you whether or not you need to read the paragraph.

Overview of Contents:

1 **Principles of Operation**
An overview of the theory of scanning probe microscopy.

PART I User's Manual

2 **Set-up, Power up, and System Test**
How to unpack and set up the instrument and run an initial system test.

3 **Preparing the Microscope for STM**
How to set up the microscope for STM, perform a manual or computer approach, and activate the feedback.

4 **Preparing the Microscope for SFM**
How to set up the microscope for SFM, perform a manual or computer approach, and activate the feedback.

5 **Scanning and Taking Images**
How to generate and store images.

6 **Image Processing Tutorial**
An introduction to the basic image processing techniques.

PART II Reference Guide

7 Mechanical Components
A description of the main mechanical components of the system: the microscope base, the heads, the translation stage, and the 120X optical microscope.

8 Electrical Components
A description of the control electronics.

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An explanation of the menu options of the Shell Program.

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An explanation of the menu options of the Data Acquisition program.

11 Image Processing Program
An explanation of the menu options of the Image Processing program.

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Customer Support and Service

Specifications and Schematics

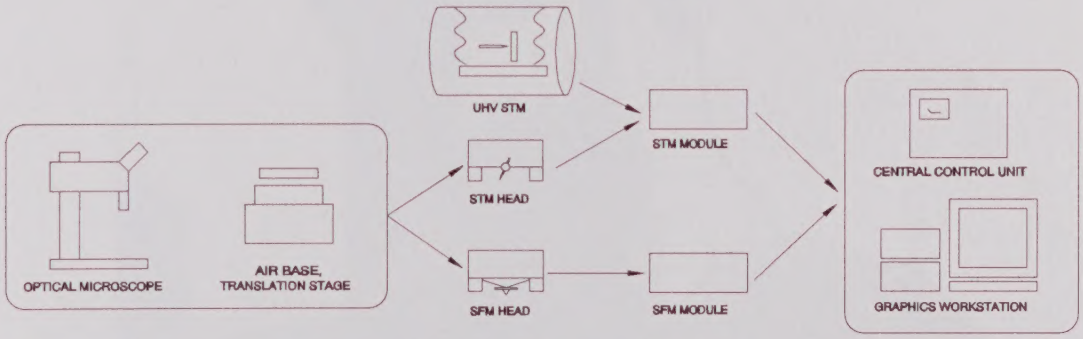
We try to keep this manual as up to date and error-free as possible. However, there are always last-minute revisions to both hardware and software, and we include them as inserts to the manual. We encourage our users to contact us with comments and suggestions.

Preface

Thank you for choosing the Park Scientific Instruments Scanning Tunneling Microscope STM-SA1 and Scanning Force Microscope SFM-BD2. This system provides scientists with unprecedented capabilities in nanometer-scale microscopy under ambient conditions. These exceptional instruments make possible nondestructive examination of conducting, semiconducting and nonconducting specimens quickly, easily, and with guaranteed accuracy. Image resolution, across the widest range of applications, meets or exceeds that of the best optical and electron microscopes, and most analyses can be performed on an ordinary table top.

The Scanning Tunneling Microscope (STM) and Scanning Force Microscope (SFM)--also known as Atomic Force Microscope--are members of a family of new microscopes called scanning probe microscopes (SPMs). In simple terms, SPMs use a sharp tip sensitive to one specific physical property to scan over a surface. The physical property of interest could be electrical, magnetic, mechanical and even thermal. In STM and SFM, tunneling current and interatomic force, respectively, are measured to gather surface topography information.

Imaging is essentially nondestructive. In STM, samples are not bombarded with high-energy electrons as they are in SEM. In SFM, the contact forces are many orders of magnitude weaker than they are in conventional stylus profilometry. SFM does not require application of a conductive coating to the sample, and virtually any material can be imaged.



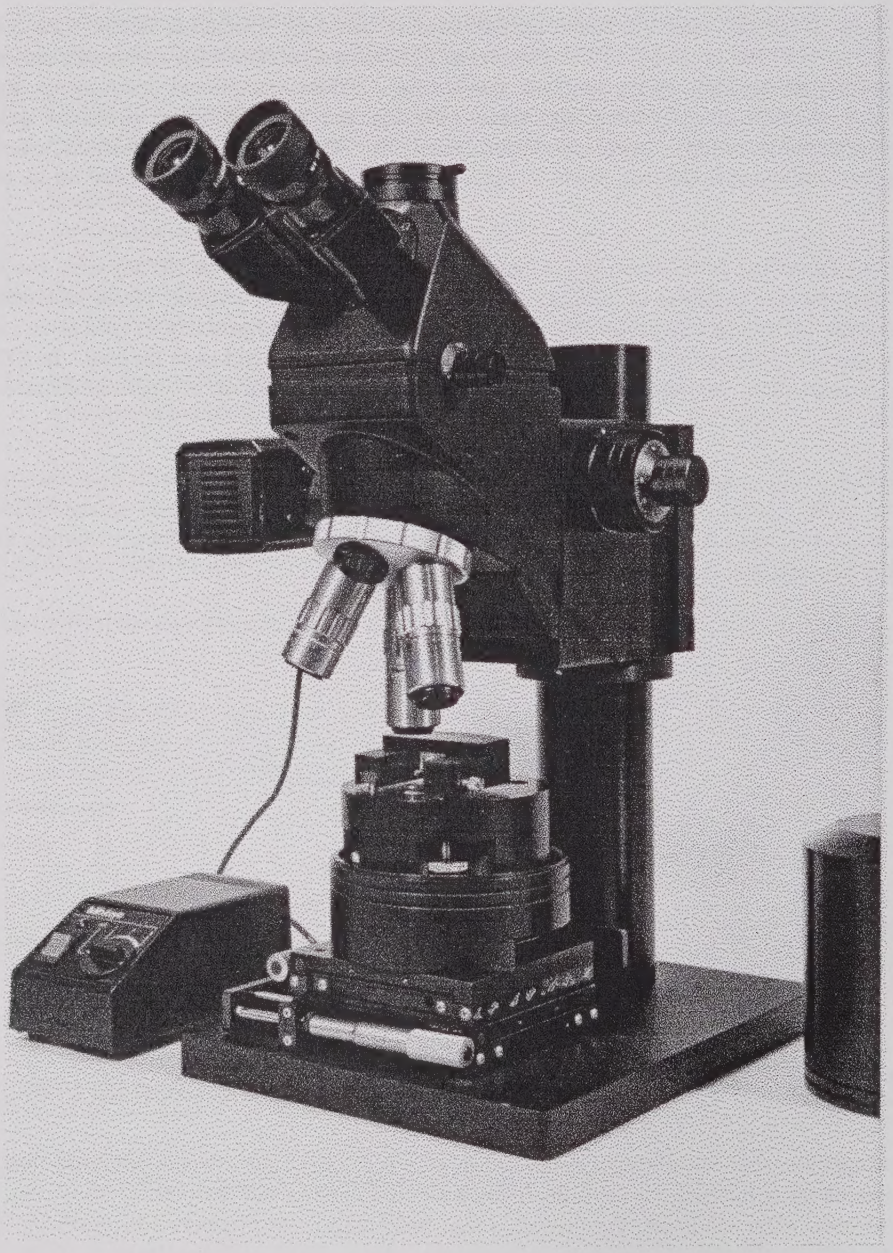
PSI's Universal SPM System

The Universal SPM: Flexibility and Cost Effectiveness

Recognizing that the field of scanning probe microscopy is just developing, and that the needs of researchers will change with time, Park Scientific Instruments has incorporated the concept of a Universal SPM with interchangeable probes in designing its products. In practice, "probe" refers not only to the transducer element (tunneling tip in STM and cantilever in SFM) but also the associated components that convert the measured physical property into a relatively linear and sufficiently large electrical feedback signal. Therefore, each probe consists of a mechanical probe housing and an electrical module. The mechanical housing contains a transducer and preamplifier circuitry, and the electrical module contains feedback circuitry with either a logarithmic (in the case of STM) or linear (in the case of SFM) input stage.

The Universal SPM is divided into the following logical components: system control workstation, central controller, feedback module, scan base and various probes. The compatibility reduces the

costs of expanding research capability while making it easy to adapt the system for custom applications with custom probes.



STM With Optional 1000X Optical Microscope

PSI's Solution to Limited Field-of-View in SPM

Locating features of interest has always been difficult with SPM, as field-of-view decreases with increased resolution. In PSI's ambient SPM, this drawback is addressed by coupling the SPM to an

optional on-axis optical microscope. The user can translate the probe so that it scans a feature of interest on the sample.

STM-SA1 or SFM-BD2, equipped with the on-axis optical microscope, various plug-in scanners and color printer, is truly a state-of-the-art instrument that can image samples ranging from atoms to integrated circuits with ultrahigh resolution and remarkable ease.

Park Scientific Instruments Warranty Statement

Warranty on New Systems and Accessories

Park Scientific Instruments (PSI) warrants to the original purchaser of the equipment that the equipment will be free from defects in material and workmanship for a period of one year from date of delivery. PSI will replace or repair, at its option, the warranted equipment at no charge to the purchaser and will perform services either at PSI's facility or at the customers facility, at PSI's option. For repairs performed at PSI's facility, the customer must contact PSI in advance for authorization to return the equipment and must follow PSI's shipping instructions.

PSI will supply replacement parts on loan, whenever possible, to enable field repair by customers with minimum downtime; once the system is operational the defective parts are then returned to PSI.

Specifically excluded from this warranty are all consumable parts including Microlevers and tips. All computer and data storage equipment not manufactured by PSI (such as computers, monitors, discs, keyboards, video and graphics printers) is warranted directly by the manufacturer. Equipment sold for use outside the United States, or equipment which has been subjected to misuse, accident, abuse, operational error, neglect, unauthorized repair, alteration or installation is not covered by this warranty.

Warranty on Replacement Parts

PSI warrants all replacement parts to be sold free from defects in materials or workmanship for a period of 90 days from the date received by the customer. PSI will repair or replace, at its discretion, such parts when returned to PSI. Customers must contact PSI in advance to obtain authorization to return parts and follow PSI's shipping instructions.

Except as herein provided, SELLER MAKES NO WARRANTIES, EXPRESS OR IMPLIED, AND SELLER EXPRESSLY EXCLUDES AND DISCLAIMS ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. UNDER NO CIRCUMSTANCES SHALL PSI BE LIABLE FOR ANY LOSS OR DAMAGE, DIRECT, INDIRECT OR CONSEQUENTIAL, ARISING FROM THE USE OR LOSS OF USE OF ANY PRODUCT, SERVICE, PART, SUPPLIES OR EQUIPMENT. NOR SHALL PSI BE LIABLE UNDER ANY LEGAL THEORY, INCLUDING BUT NOT LIMITED TO LOST PROFITS, DOWN-TIME, GOODWILL, DAMAGE TO OR REPLACEMENT OF EQUIPMENT OR PROPERTY, AND ANY COST OF RECOVERING, REPROGRAMMING, OR REPRODUCING ANY PROGRAM OR DATA STORED IN OR USED WITH PSI PRODUCTS.

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1 Principles of Operation

1.1 What is Scanning Probe Microscopy?

Scanning Probe Microscopes (SPMs) are members of a family of microscopes used for studying the surface properties of a wide range of materials with 3-D resolution at the atomic level. The two SPMs considered in this manual are the Scanning Tunneling Microscope (STM) and Scanning Force Microscope (SFM). Both of these techniques are relatively new; the STM was invented by Binnig *et al.* in 1981 and the SFM by Binnig *et al.* in 1985. The STM employs a sharp metallic tip which is scanned over a conducting sample. This technique has been shown to produce atomic resolution images of many conducting surfaces and to measure their local electronic spectra. SFM is an offshoot of STM that lets the user study the topography not only of conductors (the only samples with which STM can be used), but also of non-conductors with comparable resolution.

1.1.1 Physical Basis of STM

When a sharp metallic tip is brought to within a few angstroms of a conducting surface, a tunneling current will flow between the tip and surface. The magnitude of this current depends exponentially on their separation. In Scanning Tunneling Microscopy this current is used in a feedback circuit along with a transducer element (usually a piezo electric device) to control the tip-sample separation with sub-angstrom precision in all three directions. By raster scanning the tip over the surface and monitoring the Z position of the transducer element (its extension towards the sample), atomic resolution images of the surface can be generated. Key to the success of this technique is that the tunneling current is localized to the atom of the tip nearest the sample, due to the exponential fall-off of the tunneling current with distance from the sample.

1.1.2 Physical Basis of SFM

SFM, like STM, uses a very sharp probe (the SFM tip) to limit the interaction area on the surface being studied. Whereas the STM measures the current derived from electrons that tunnel from the surface to the tip, the SFM measures a contact force (typically van der Waals in origin) between the tip and the surface. The tip is at the free end of a cantilever of known force constant, and the force is determined by measuring the deflection of the cantilever as the tip makes contact with the surface. These contact forces fall off very quickly with increasing distance from the surface. The fall-off keeps the interaction confined primarily to the very end of the SFM tip, allowing high resolution imaging--just as the exponential dependence of tunneling current on sample-tip separation is exploited for high resolution imaging in STM. In this microscope the sample is raster scanned and a constant cantilever deflection is maintained by a feedback circuit.

1.1.3 Components of All SPMs

Fig. 1-1 illustrates the basic components found in every SPM: (a) a sample to be imaged, (b) a probe, (c) a Z-deflection sensor, (d) an actuator whose vertical position is controlled by the feedback electronics and whose lateral position can be raster scanned, (e) a coarse positioning system to bring the probe and sample to within the range of the actuator

element, (f) feedback electronics to maintain a constant sensor output (e.g. constant current or constant lever deflection), (g) a scan generator, and (h) a display.

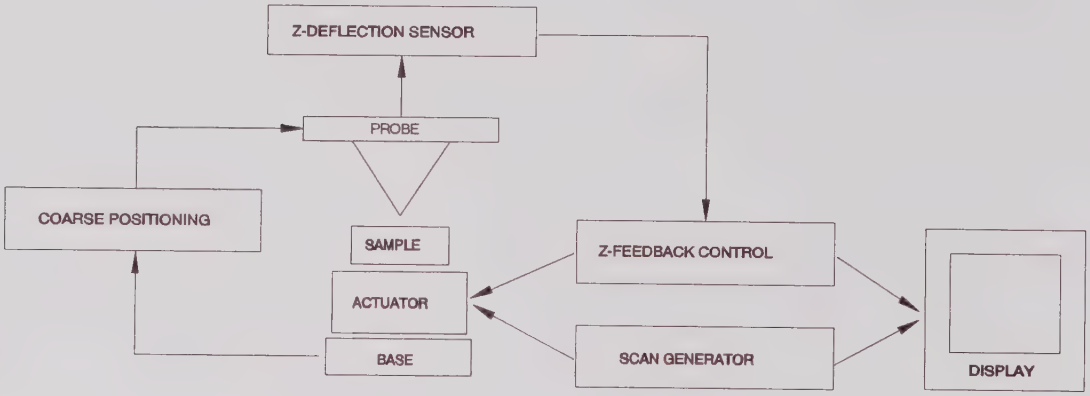


Fig. 1-1 Components of All SPMs

An image is made by recording the feedback signal, which is directly proportional to the vertical displacement of the actuator and is necessary for maintaining a constant sensor output as the sample is scanned laterally.

1.1.4 SFM Detection Mechanisms

Whereas detecting the change in tip-sample separation with STM (i.e. measuring the tunneling current) is reasonably straightforward, there are several different detection schemes used with SFM. Fig. 1-2 shows different kinds of sensors that have been used to measure the deflection of a cantilever in SFMs. Binnig, Quate and Gerber used a tunneling tip to measure the deflection of a microfabricated cantilever which had a conductive gold coating on the back (a). Many groups around the world use optical interferometry, in which light from an optical fiber reflects off the back of the cantilever and interferes with light that reflects at the fiber-air interface (b). Other methods use capacitive sensing or piezo-resistant measurements.

The mechanism used in PSI's SFM is optical lever deflection (c), a relatively simple technique for measuring sub-angstrom displacements of the cantilever. Its operation is illustrated in Fig. 1-3. A light source is focused onto the back side of the cantilever near the tip end. The light reflects off the cantilever into a position-sensitive photodetector (PSPD). As the cantilever deflects, the reflected light spot moves across the PSPD, and the output of the detector changes. The PSPD can measure a displacement of light at the detector as small as 10 angstroms. Because of the angular magnification of the reflected beam this displacement corresponds to sub-angstrom motion of the cantilever tip.

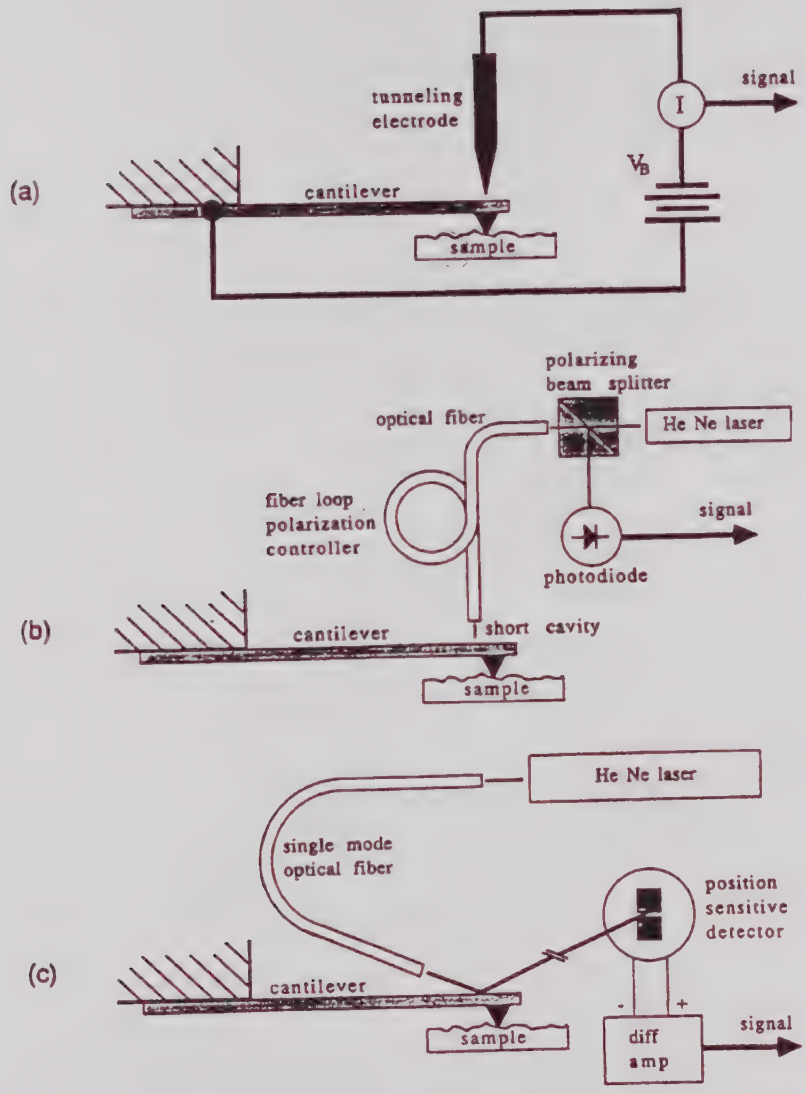


Fig. 1-2 SFM Detection Mechanisms

1.2 PSI's SPM

This section provides a more detailed description of the PSI instruments.

The microscope heads house the SPM probes. The base has the actuator and coarse positioning system (the approach screws). The Control Modules house the feedback electronics and other functions. The Central Control Unit (CCU) contains the scan generation and oscilloscope display and controls the coarse positioning system. The computer displays, stores and processes the data.

Park Scientific Instruments has designed its electronics so that those components of a scanning microprobe system that are common to all of PSI's products are contained in one box, the CCU. Electrical components peculiar to each instrument are contained in separate boxes, the Control Modules. This keeps the price of adding additional SPM capabilities to a minimum, whether STM, SFM, or some future scanning microprobe technique.

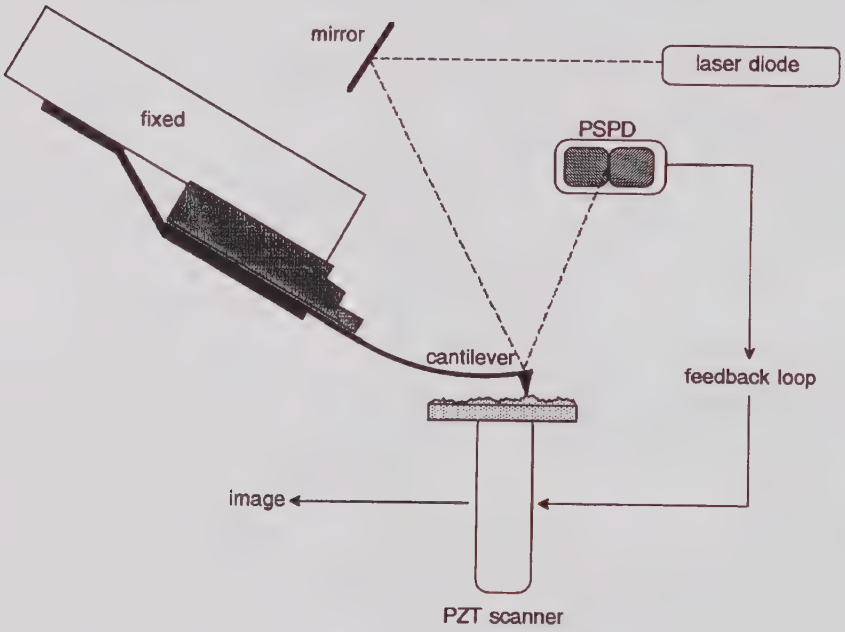


Fig. 1-3 Optical Lever Deflection in PSI's SFM

1.2.1 The STM Probe

The STM Tip: STM tips are almost always made from metallic wire; tungsten and platinum-iridium are the most common materials. Tips with atomically sharp points can be made in several ways. One common method for sharpening tungsten wire uses an AC electrochemical etch. If a piece of tungsten wire is partially submerged in a KOH solution and used as one electrode, the wire will etch on all sides, bringing the end to a sharp point. This is a relatively quick and reproduceable procedure. Making STM tips from platinum-iridium wire is even simpler. By cutting the wire at an angle with wire cutters an atomically sharp tip can be formed. Both of these procedures can be performed by the user, and it is best if tips are made just prior to use.

The tips are held by a set screw on the STM head. With this head the orientation of the tip with respect to the sample can be adjusted. Using tungsten tips oriented perpendicular to the sample, features with the highest aspect ratios can be imaged. If the tip is rotated off normal, an optical microscope can be placed directly above the sample, and the tip-sample region can be viewed on-axis. Using the coarse X/Y translation stage and a high-powered

optical microscope, the user can place the tip over a desired area on the sample with high precision.

The STM Sensor: Measuring the tunneling current is straightforward. The current from the STM tip goes directly into a current-to-voltage amplifier located only a few centimeters from the tip in the head. A nanoamp of current is amplified to 1 volt by this amplifier, and the signal is input into the feedback circuit.

1.2.2 The SFM Probe

The Cantilever: PSI's Microlevers are fabricated using micromachining techniques on Si. The result is a wafer with several hundred chips; each chip has six cantilevers with integral pyramidal tips (see Fig. 1-4). It is a good idea to study the wafer under an optical microscope to become familiar with the size and location of the Microlevers. Chips are held together with spacers in strips. Remember that the Microlevers are on the top surface of the strips and extend out on either side, so do not let anything touch the tops or sides of the strips.

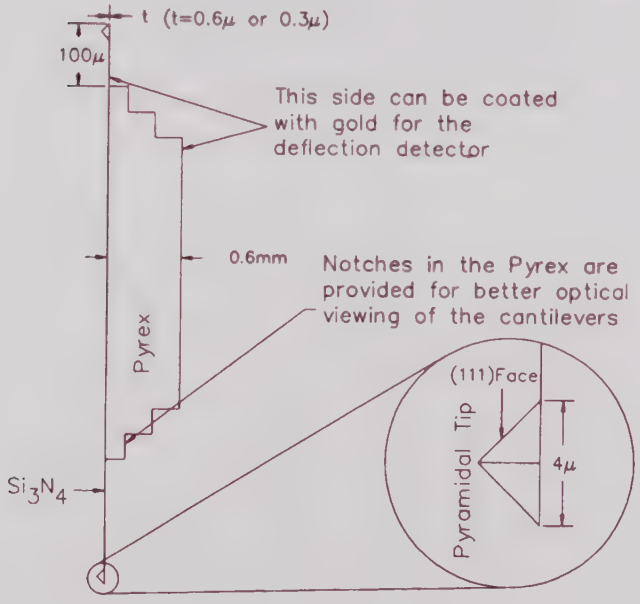


Fig. 1-4 Chip with Microlevers

Observe that each chip has six Microlevers. Each has a different force constant so that you can choose the Microlever appropriate for your application. Tools are provided for removing the Microlever chips in the Chip Handling Tool Kit. Appendix 6A explains how to remove the chips.

How the microscope holds the Microlever and how the Microlever tip comes into contact with the sample are very important. In PSI's SFM a leaf spring clip holds the chip in place. The mount holds the chip in a specific location, facilitating laser realignment when chips are replaced, and at a specific angle, about 15° from the plane of the sample. This angle is important because only the tip of the Microlever should make contact with the sample surface, as illustrated in Fig. 1-5.

If the angle is much less than 15°, the chip may touch the sample, and if it is a more than 15°, the end of the Microlever may touch the surface. The first case would clearly not be low-force imaging. The second would give poor resolution, as the end of the Microlever is not as sharp as the pyramidal tip. Particular attention must be paid to this angle when the sample surface is tilted or spherical. By adjusting the fine and coarse-approach screws that support the SFM head, the angle can always be adjusted properly so that the tip of the Microlever will touch the surface first.

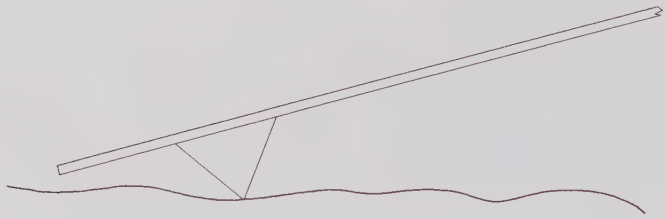


Fig. 1-5 Microlever Tip Contacting Sample

There is a second important angle to be aware of. The front end of the Microlever chip must be parallel to the sample surface so that the corners of the chip will not touch the sample before the Microlever does. This is illustrated in Fig. 1-6.

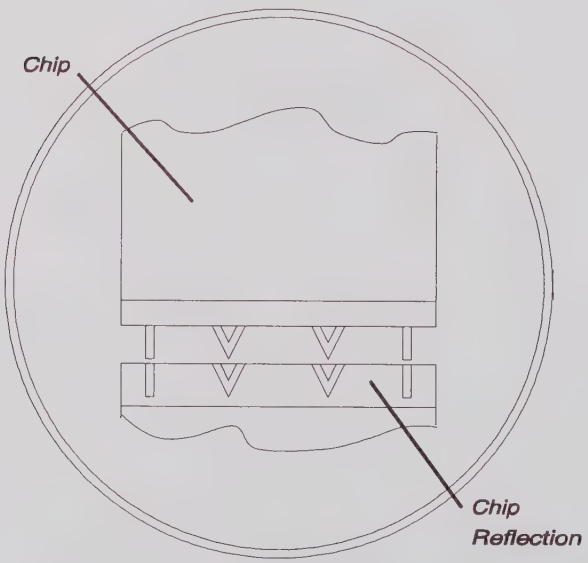


Fig. 1-6 Microlever Chip Parallel to Sample Surface

If the sample is reflecting, the chip can be made parallel to the sample surface by making the chip edge and its reflection parallel. This will insure that the Microlever will touch the sample first. This angle is controlled by moving the two coarse-approach screws independently, shown in Fig. 1-7, thereby tilting the head with respect to the sample.

At first this procedure may seem difficult, but with just a little practice the user can set the SFM head in its proper orientation in a few minutes.

Fig. 1-7 Coarse-approach Screws

The Optical Lever-Deflection System: PSI's SFM uses an optical-lever deflection system to measure the deflection of the cantilever. The entire sensor, including electronics, is located in the SFM head.

A laser diode with collimating and focusing optics is located in the head; the back of the laser diode can be seen from the back of the SFM head. A lens inside the laser diode unit focuses the light. As the light is focused, it reflects off a steerable mirror; the mirror is held in a mount whose orientation can be finely controlled by two adjustment screws on the top of the SFM head. The light is steered onto the back of the Microlever, at which point the laser spot is focused. It reflects off the Microlever, diverges, and strikes the position-sensitive photo-detector (PSPD). The PSPD is mounted on a slide whose motion is along the same axis as that along which the laser beam is moved by deflection of the Microlever. You should turn the mirror steering screws and PSPD positioning screws to become familiar with their functions.

1.2.3 The Actuator: The Piezo Tube

A key element in all SPMs is the device used to change the relative position of the probe and sample to subangstrom resolution in all three directions. This device is controlled by voltage signals originating from the feedback circuit and the scan generator. The most commonly used actuator for SPMs is a piezoelectric scanner. Piezoelectric materials have the property that they contract or expand when a voltage is applied across them.

When the STM was first invented, the scanner was formed by configuring three piezoelectric bars into a tripod, allowing motion in three orthogonal directions. These actuators have a limited throw, typically about 1 micron. This is adequate for imaging homogeneous samples with small features.

To increase the throw of the scanner and its resonant frequency, Smith et al. invented a new scanner made of a single piezoelectric tube in 1985. The tube has 5 electrodes. The inside of the tube is one complete electrode, and voltage changes applied to it relative to the outside of the tube extend or contract the tube along its axis, usually defined as the Z direction. The outside electrode is scribed axially into 4 quadrants, as illustrated in Fig. 1-8. Applying one of the raster scan signals to one pair of opposite electrodes scans the tube in one direction (the X direction), and applying the other raster signal to the other pair of electrodes scans it in the orthogonal direction (the Y direction). Such tubes can have very thin walls, thus increasing the throw of the scanner. The X and Y scan sizes increase quadratically with tube length. These tubes have high resonant frequencies and can be scanned at near video rates.

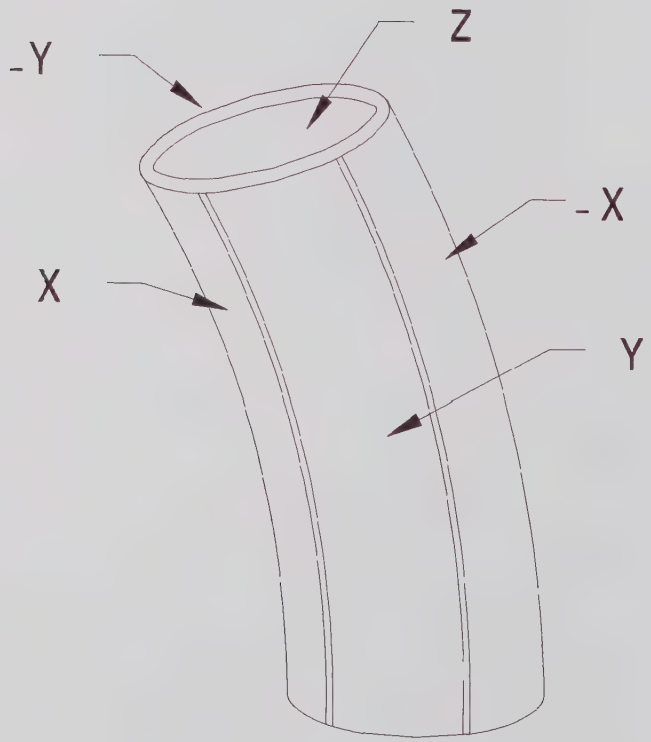


Fig. 1-8 Piezoelectric Tube Scanner

A variety of tube scanners are used with PSI's ambient systems to cover a wide range of applications. For atomic-scale studies the 2.5 μ scanner is appropriate. (The maximum X-Y scan range is 2.5 μ; the Z throw is about 1.2 μ.) PSI also offers 10 μ, 35 μ and 75 μ scanners with Z throws of 2.5 μ, 5 μ and 7 μ, respectively. For any given application the tube with smallest throw capable of scanning the desired range should be used so as to minimize electrical noise.

1.2.4 The Positioning System

In the microscope base are three fine-pitch approach screws upon which the STM or SFM head rests. Two are coarse-approach screws which are turned manually to bring the STM or SFM tip close to the sample. The 120X optical microscope provided is used to look at the tip-sample region during manual approach. As mentioned in Section 1.2.2, the coarse-approach screws also adjust the tilt of the SFM head to compensate for sample tilt.

The third screw is turned by a stepper motor in the base. This motor is controlled by the Central Control Unit. If the COMP/MAN switch on the SAMPLE APPROACH panel on the CCU is set to MAN, you can drive the motor with the FWD/BWD switch on that panel. FWD moves the tip toward the sample, and BWD moves it away. The speed can be controlled on the same panel.

There are ball bearings on the tops of the three approach screws. These three points support and locate the microscope head in a kinematic mount.

Kinematic Mounting: The STM and SFM heads attach to a translation stage, which is described in Section 7.4. There are three different mounting surfaces on the translation stage which rest on the ball bearings of the approach screws as shown in Fig. 1-9.

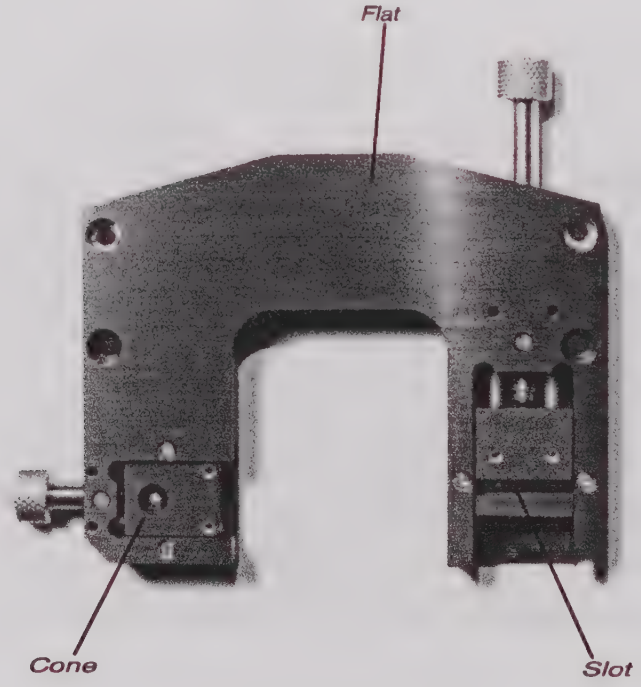


Fig. 1-9 Kinematic Mount

A conical indentation on the translation stage fits over the right coarse-approach screw, and a slot fits over the left coarse-approach screw. The fine-approach screw makes contact with a flat surface. With this mounting scheme the head can be removed and replaced to within a few microns of its original position. It also provides a mechanically stable yet removable mounting of the microscope head.

The conical and slotted mounting points are on slides whose position can be adjusted by two fine pitch screws, as shown in Fig. 1-9. These screws allow precise positioning of the STM or SFM tip anywhere within in a 5 mm x 5 mm window. The tip can thus be positioned over a feature of interest on the sample to within a few microns using an optical microscope.

1.2.5 Feedback Electronics: The Control Modules

The STM and SFM Control Modules use the output signals from the STM and SFM heads in a feedback loop. The speed and gain of the feedback loop are controlled on the front panels of the Control Modules. The position of the Z piezo can be controlled by feedback, withdrawn, or controlled manually on the Control Module. During a computer-controlled approach, the computer controls the position of the Z piezo. The preamp signals and the Z piezo signal can be amplified before the computer reads them. This allows efficient use of the A/D converters to generate images with maximum resolution.

1.2.6 The Scan Generator (CCU SCAN CONTROL Panel)

The CCU controls the scanning signals, including the size, position, and orientation of the scan region. (The CCU also houses the stepper motor control, an LED display showing the positions of the X,Y, and Z piezo elements, and an oscilloscope to monitor the data in real-time.)

1.2.7 The Display

Oscilloscope: The CCU has an internal oscilloscope to monitor, in real-time, the data from the microscope as a function of the scan--it displays linescan data at all times.

This scope is a valuable tool for optimizing scan and feedback parameters. It provides a continuous view of the scanning signal and topography, and the effects of changes in scan size, feedback gain, scan rotation, and other parameters can be viewed in real-time.

The gain and time constant of the feedback loop in particular should be set while watching the trace on the scope. Fig. 1-10 shows the scope trace during a scan of a calibration grating with one micron period. The gain is low and time constant high, so little substructure appears in the trace. (A forward and backward trace are shown; because of hysteresis they do not coincide.)

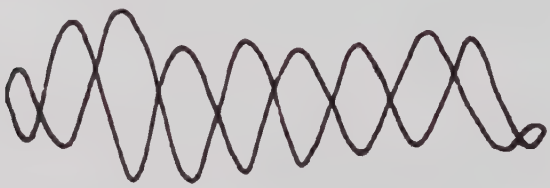


Fig. 1-10 Calibration Grating Trace at Low Gain and High Time Constant

If the gain is increased and the time constant reduced, the trace will more accurately represent the surface topography. Fig. 1-11 shows the scope trace of the same grating for which feedback parameters have been optimized.

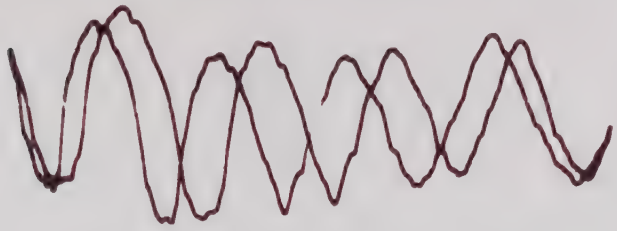


Fig. 1-11 Calibration Grating Trace with Feedback Parameters Optimized

If the feedback gain is increased further or the time constant decreased further, the system will oscillate. Fig. 1-12 shows the scope trace of the grating in this case. To optimize the feedback parameters the feedback gain should be turned down or time constant turned up so that the system is just below this oscillation point. In this way the scope allows optimization of parameters for imaging.

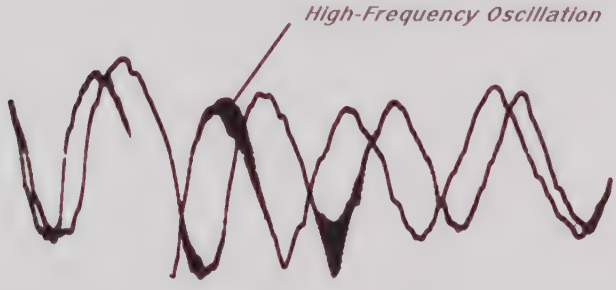


Fig. 1-12 Calibration Grating Trace Showing Oscillation

The CCU also houses all of the computer interface cards, including the A/D and the D/A converters for the scan signals and for data acquisition. The CCU communicates with the computer, an HP 340 series workstation. The CCU also sends signals to and receives signals from the Control Modules and the microscope heads.

HP Computer: The final component of the PSI SPM system is the HP workstation. This computer controls many of the scan parameters and acquires the data. It also has an extensive library of image processing software to help generate the best possible image.

The HP 340 series workstation communicates to the CCU via the GPIB. In data acquisition mode the user interacts with the computer through menu keys and sets various parameters like scan speed, number of pixels per image and real-time scan non-linearity corrections. The computer initiates a scan by sending a clock signal to the CCU. It reads the image data as the piezo is being scanned and displays this data in both gray-scale and amplitude-trace formats.

Several images (up to 48 128 x 128 pixel images) can be stored in the computer's internal memory. These images can be saved to the hard disk with a header file that can be changed for appropriate labeling of the data. The data can be recalled later for image processing. This software will be discussed in chapters 10 and 11.

Part I
User's Manual

The following five chapters provide step-by-step instructions for the operation of PSI's STM-SA1 and SFM BD2. The user is guided through every procedure, from the unpacking of the instrument to the printing of the data in its final form. For questions regarding a particular part or function, refer to the Reference Guide (Part II).

2 Set-Up, Power Up and System Test

Preparing the Operating Environment
Necessary Tools and Materials
Unpacking and Set-up
Computer Start-up
System Test

Warning: Use of controls or adjustments, or performance of procedures other than those specified herein may result in hazardous laser light exposure.

Caution: To avoid damage to the instrument, follow these set-up instructions carefully. Be particularly careful with the piezo scanner and the SFM laser diode. Both can be damaged by improper use.

Fig. 2-1 Piezo Scanner

2.1 Operating Environment

Before unpacking or setting up the instrument, give careful consideration to the operating environment. A recommended set-up is illustrated schematically in Fig. 2-2. Chapters 3 and 4 provide further detail.

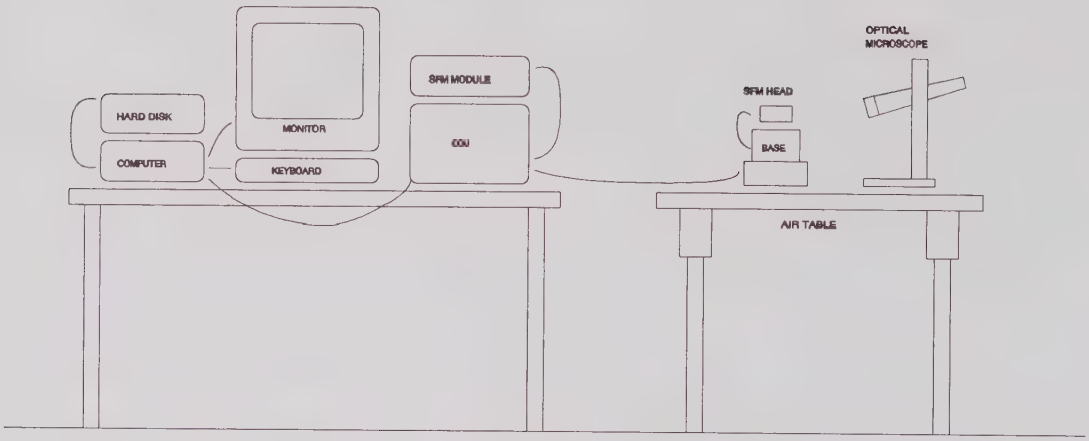


Fig. 2-2 Recommended Set-Up

Select the room, ideally in the basement.

+ The room should be as free of mechanical vibrations as possible.
+ The room should be free of acoustical noise, such as noisy ventilation.

Consult PSI if your room does not meet either of these conditions.

Prepare a separate, vibrationally-isolated table for the STM and SFM heads, base, and optical microscope.

+ A solid, stable table is satisfactory for imaging large features.
+ An air table or similar table is needed for atomic resolution work.

Prepare other tables or racks.

+ Prepare tables or racks for the electronics and computer.
+ Prepare an area for STM tip preparation and Microlever work.

2.2 Necessary Tools and Materials

Some tools and materials have not been included in the package:

+ Power strip
+ Wire cutters for preparing PtIr or tungsten STM tips
+ Deionized water for tip etcher
+ Glass stirring rod for tip etcher solution
+ Beakers for water and alcohol to rinse etched STM tips
+ Needle-nosed pliers or tweezers for STM tip handling
+ Metal plate for Microlever work surface (recommended)
+ Box to cover strips of Microlever chips separated from wafers

2.3 Unpacking and Set-Up

Before unpacking, check the packing list to make sure that all boxes have arrived. If not, notify PSI personnel immediately.

While unpacking, make a note of any damage. Save shipping materials in the event that you want to send the instrument back to PSI for an upgrade.

Warning: Use of controls or adjustments, or performance of procedures other than those specified herein may result in hazardous laser light exposure.

Caution: Be careful when unpacking the STM and/or SFM, as they are delicate.

Ensure that the system ground wire is connected to a reliable ground and that the same power strip is used for all system components.

2.3.1 Control Electronics

Unpack the control electronics.

+ Unpack the Scanning Microprobe Central Control Unit (CCU)
+ Unpack the STM Control Module if applicable
+ Unpack the SFM Control Module if applicable
+ Unpack one power cord and the two 25-pin interface cables

Caution: Make sure the CCU is set to the correct local voltage on the back panel.

Set up the control electronics. They should be near the table for the STM and SFM heads and base.

+ Stack the Control Modules on top of the CCU
+ Plug in the power strip
+ Plug the CCU into the power strip with the power cord
+ Do not turn anything on yet

2.3.2 Computer System

The HP 340 series workstation is a powerful computer. We strongly advise you to review the pertinent parts of the HP manual.

Unpack the components of the computer system.

+ Unpack the CPU, its power cord, and the RGB cable (monitor cable)
+ Unpack the hard disk drive and its power cord
+ Unpack the monitor and its power cord
+ Unpack the 1m and 4m HPIB cables
+ Unpack the keyboard, the keyboard cable, and the mouse.

Caution: Make sure the computer components are set to the correct local voltage on the back panel.

Connect the computer components following the HP pictorial instructions.

+ Plug in the CPU, hard disk drive, and monitor with their power cords
+ Connect one end of the 1m HPIB cable to the HPIB port on the CPU
+ Connect the other end of the cable to the hard disk drive
+ Connect the CPU and monitor with the RGB cable
+ Connect the keyboard to the CPU with the keyboard cable
+ Connect the hard disk drive to the CCU using the 4m HPIB cable

2.3.3 Microscope

Prepare the table for the microscope. Set up the air table, if available, following the manufacturer's instructions.

Unpack the microscope components.

+ Unpack the ambient STM/SFM base and cover
+ Remove the tape holding the base and cover together
+ Unpack the STM head and/or SFM head

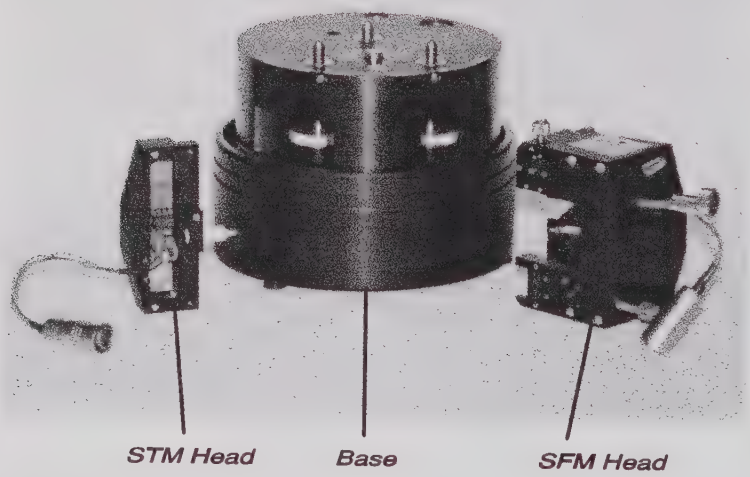


Fig. 2-3 Microscope components

2.3.4 120X Optical Microscope

Unpack the components of the 120X optical microscope and fiberoptic lightsource with gooseneck lightpipe.

+ Unpack the base and stand
+ Unpack the 120X optical microscope body
+ Unpack the adjustable mount
+ Unpack the 2X multiplier
+ Unpack the fiberoptic lightsource
+ Unpack the gooseneck lightpipe and lens

Assemble the 120X optical microscope:

+ Use a crescent wrench to attach the stand to the base
+ Attach the adjustable mount to the stand
+ Screw the 2X multiplier onto the objective of the 120X optical microscope
+ Insert the 120X optical microscope into the mount

Assemble the fiberoptic lightsource with gooseneck pipe:

+ Spread out the support feet on the fiberoptic lightsource
+ Screw the gooseneck pipe into the fiberoptic lightsource
+ Attach the lens onto the gooseneck pipe

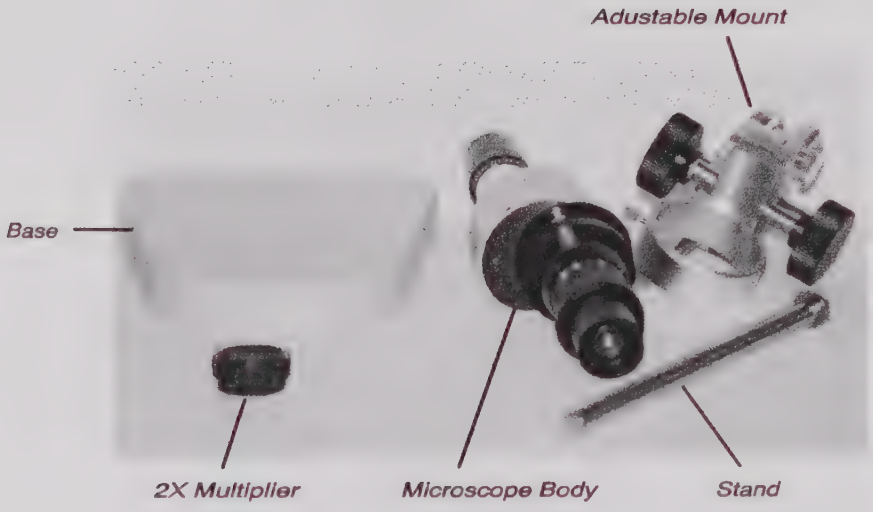


Fig. 2-4 Components of Optical Microscope

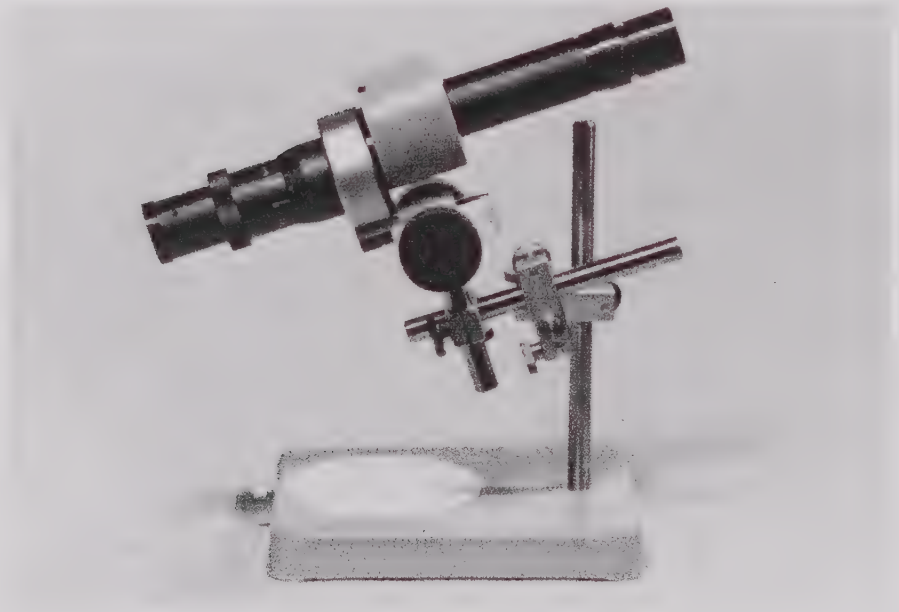


Fig. 2-5 Assembled 120X Optical Microscope

2.3.5 Remaining Components

The following items should also be included:

+ Chip Handling Tool Kit (for SFM only)
+ Microlever wafer (for SFM only)
+ STM tips (for STM only)
+ Operator's tool kit (includes allen wrenches and screwdriver)

+ Sample stubs and case, including gold calibration grating
+ Software

For unpacking and set-up of the tip etcher, refer to Appendix 3C; for the 1000X optical microscope, refer to Appendix 2A.

2.4 Computer Start-Up

Turn on the computer, hard disk drive, and monitor. The computer will boot automatically, then load the BASIC operating system and search for the PSI AUTOST program (**Shell Program**). It will automatically run the Shell Program, and the PSI screen will appear. There are several programs on the hard disk drive, including the Data Acquisition program (**SPM*_***) and Image Processing program (**IP*_***). (Asterisks refer to the current versions of the program; the software is continually being updated.)

2.5 System Test with STM

We recommend performing a quick system test. If you have an STM, use it for this test, since its operation is more straightforward. If not, skip down to Section 2.6, "System Test with SFM."

Caution: This section contains only quick instructions for a system test. It does not provide complete instructions for running the system in a variety of circumstances. Failure to read the following chapters on running the system may risk damaging the sample, wasting time, and damaging the instrument.

2.5.1 Setting up the Microscope

(Refer to Section 3.1 for greater detail.)

Use either a 2.5 μ or 10 μ scanner for the system test.
Put the base on the prepared table.
With the CCU off, connect the base to the CCU with the 25-pin interface cable.
Put the calibration grating into the sample holder on the base.

Caution: The sample holder is attached to a piezoelectric tube (scanner) which is very delicate. Be careful when tightening the set screw, as too great a torque may break the tube.

Gently tighten the set screw on the sample holder.

Warning: Be aware that the piezo scanner carries high voltage, although the sample stub is well insulated from this voltage.

Remove the translation stage from the SFM head by loosening the 4 bolts.
Attach it to the STM head with a 3/32" allen wrench, using the same 4 bolts.
Plug the 12-pin connector of the STM head into the base.
Stand the head on its side on the base.

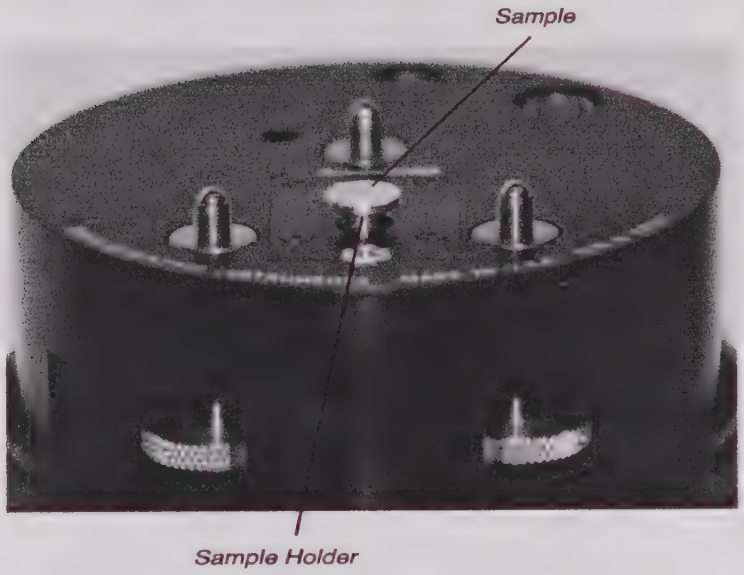


Fig. 2-6 Sample Stub in Sample Holder

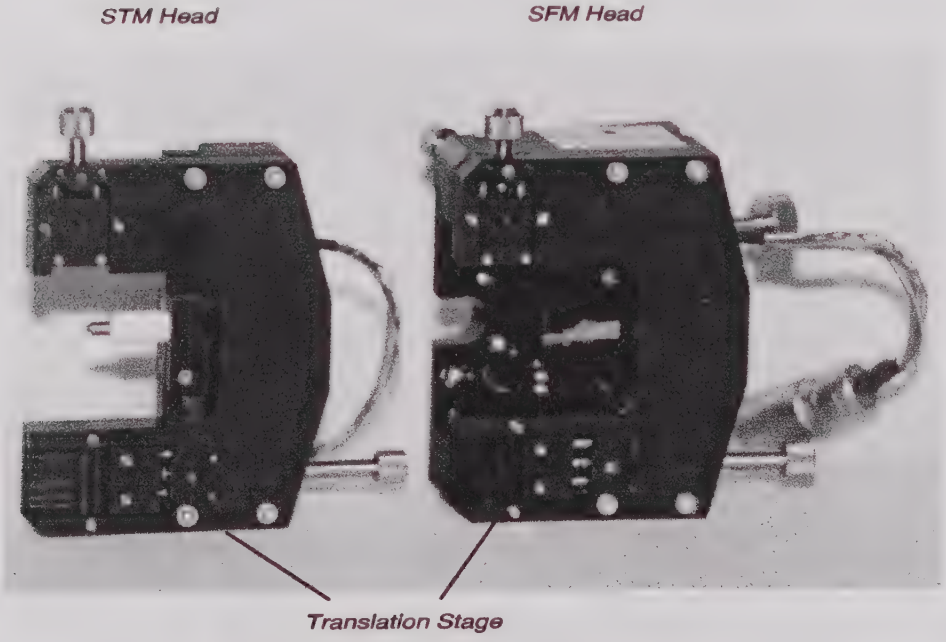


Fig. 2-7 Translation Stage on SFM and STM Heads

Insert the blunt end of one of the STM tips provided into the holder.
Tighten the set screw gently with an allen wrench.
Raise the thumb screws on the base so the tip will not hit the sample.
Set the STM head on the three approach screws.

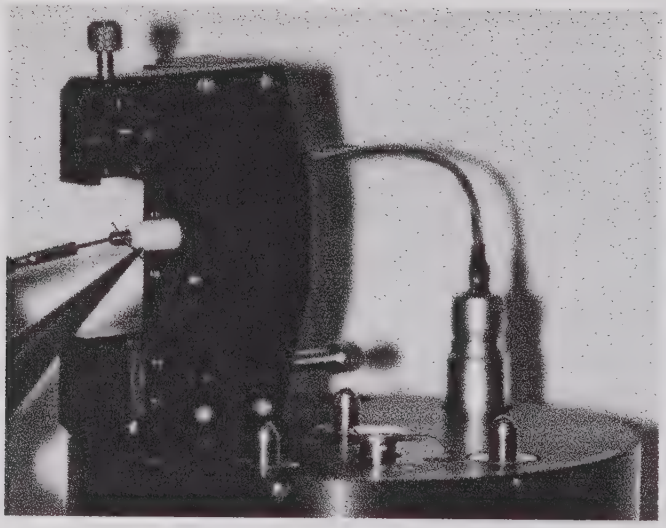
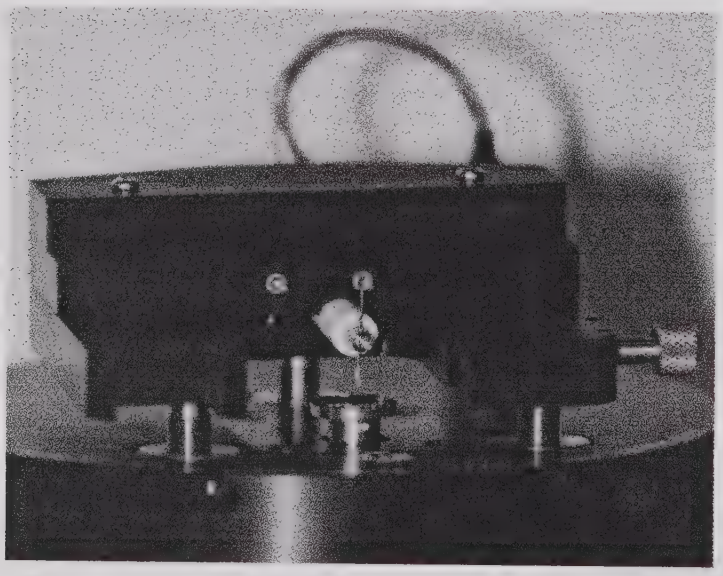


Fig. 2-8 Putting the Tip in the STM Tip Holder



2-9 STM Head on the Base

2.5.2 Manual Approach

(Refer to Section 3.2 for more details.)

Position the 120X optical microscope in front of the base and head.
Look at the tip and the sample through the optical microscope.
Adjust the translation positioning screws until the tip is centered over the sample.

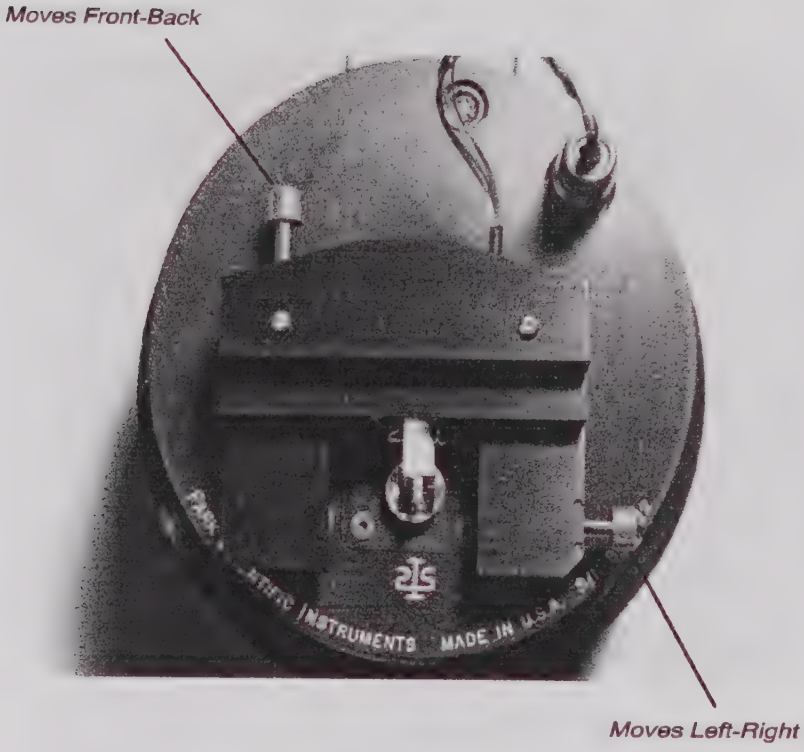


Fig. 2-10 Translation Stage Positioning Screws

Turn the thumb screws to lower the head toward the sample.
Watch the tip approach its reflection.
Bring the tip as close as possible to, but not touching, the grating.
Put the cover on the base.

2.5.3 Performing a Computer Approach

(Refer to Section 5.1 for more details.)

On the STM Control Module:

Connect the STM Control Module to the CCU with a 25-pin interface cable.
Set CURRENT to 1 nA.
Set VOLTAGE to 0.2 V.
Set FAST FEEDBACK GAIN to minimum.
Set SLOW FEEDBACK to COMP.
Set DC LEVEL to TRACK.
Ignore the TEMPERATURE panel.

On the CCU:

Turn on the power.
Set the X0 AXIS and Y0 AXIS SCAN SIZE knobs to 0.
Set the X AXIS and Y AXIS X10 DC OFFSETs to 5.
Set the COMP/MAN switch to COMP.

On the Computer:

Select SPM Data Acq.
Find the trace on the scope with the slope control knobs.
Turn up the scope gain.
Select the Move Sample menu.
Select the Auto Approach option.
Type <Return> to accept the default (ten steps).

2.5.4 Activating Feedback

(Refer to Section 3.3.4 for more details.)

Wait for the computer approach to finish.
Set the TIME CONSTANT on the STM Control Module to 6 for a 2.5 μ scanner, or 10 for a 10 μ scanner.
Set FAST FEEDBACK GAIN to 3.
Switch SLOW FEEDBACK to AUTO.

2.5.5 Taking an Image

On the computer:

(Refer to Section 5.1.1 for more details.)

Select EXIT and then the Set-up Menu.
Select the X Scan Rate option.
When prompted, enter 2 and press <Return> to change the scan rate.
Select the Extended Configuration option.
Set the piezo sensitivity to the values indicated on the tube. They should be close to those given in the table below.

Scanner	Z	X,Y
2.5 μ	40	60
10 μ	80	240

On the STM Control Module:

(Refer to Section 5.2.1 for more details.)

Set SOURCE to Z.
Set the IMAGE ACQUISITION GAIN to 1.

On the CCU:

(Refer to Sections 5.2.2 and 5.3.2 for more details.)

Set the SCOPE MONITOR switch to IMAGE DATA.
Turn up the scope gain.
Set the SCAN SIZE MULTIPLIER to 100.
Set the Y0 SLOPE to 0.
Set the ROTATION to 0.
Set the X0 AXIS and Y0 AXIS SCAN SIZES to 9.5 for a 2.5 μ scanner, or 4 for a 10 μ scanner.
Rotate the X0 SLOPE until the trace is horizontal.

On the computer:

(Refer to Section 5.5 for more details.)

Exit the Set-up menu to the Main Level.
Select the Take Data option.
Select Take Image.
Select Display Options.
Select Display Amplitude.
Type 2000,0 and press <Return>.
The image should look like that shown in Fig. 2-11.

Fig. 2-11 STM Image of Grating

2.5.6 Shutdown:

Switch SLOW FEEDBACK to WDRW on the STM Control Module.
Toggle the COMP/MAN switch on the CCU to MAN.
Toggle the FWD/BWD switch to BWD.
Turn up the SPEED.
Back up 400 steps, then stop the motor.
Turn off the CCU.
Reduce the brightness of the monitor.

2.6 System Test with SFM

Set up the SFM system if you do not have an STM system. SFM is inherently more complicated than STM, so read the instructions carefully.

Warning: Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous laser light exposure.

Caution: The laser diode is easily damaged; treat it with care. Plug and unplug the SFM head with the SFM Control Module off. Avoid applying external voltage to the metal casing of the head.

Caution: This section contains only quick instructions for a system test. It does not provide complete instructions for running the system in a variety of circumstances. Failure to read the following chapters on running the system may risk damaging the sample, wasting time, and damaging the instrument.

2.6.1 Putting the Chip in the Head

Prepare a Microlever chip following Appendix 4A.
Install the chip in the SFM head following Section 4.1.

2.6.2 Setting up the Microscope

(Refer to Section 4.2 for more details.)

Warning: Do not plug in the 12-pin connector yet. To avoid exposure to laser light, the connector should not be connected until the head is in place. Laser power should also be turned off on the SFM Control Module.

Use either a 2.5 μ or 10 μ scanner for the system test.
Put the base on the prepared table.
With the CCU off, connect the base to the CCU.
Put the calibration grating into the sample holder on the base.

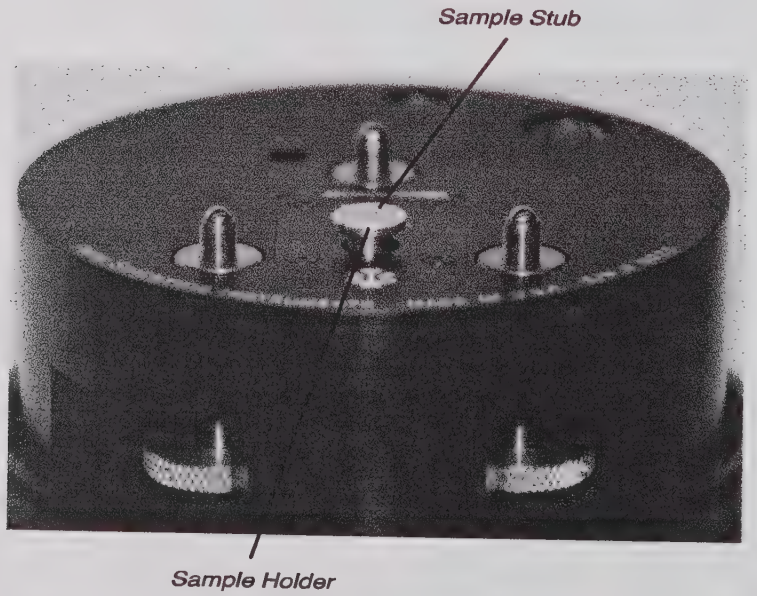


Fig. 2-12 Sample Stub in Sample Holder

Caution: The sample holder is attached to a piezoelectric tube (scanner) which is very delicate. Be careful when tightening the set screw, as too great a torque may break the tube.

Gently Tighten the set screw on the sample holder.

Raise the thumb screws on the base so that the tip will not hit.
Set the SFM head on the three approach screws on the base.

2.6.3 Positioning the Laser

(Refer to Section 4.3 for more details.)

Connect the SFM Control Module to the CCU with a 25-pin interface cable.

Caution: Do not plug the 12-pin connector of the SFM head into the base with the laser power turned on. It will reduce the lifetime of the laser.

Make sure the LASER POWER is off on the SFM Control Module.
Plug the 12-pin connector on the SFM head into the base.

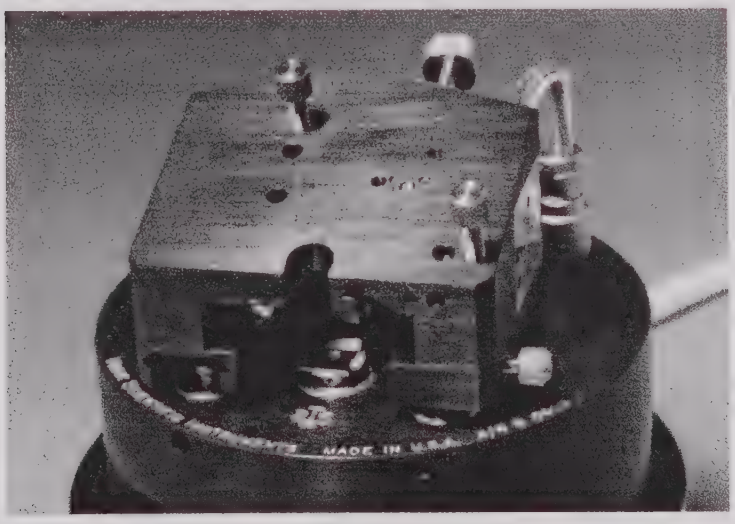


Fig. 2-13 SFM Head on the Base

Turn on the CCU power.
Turn on the LASER POWER on the SFM Control Module.
Position the 120X optical microscope in front of the base and head.
Position the laser spot on the Microlever following Section 4.3.

2.6.4 Manual Approach

(Refer to Section 4.4 for more details.)

Position the Microlever with the translation stage positioning screws so it is over the center of the grating.

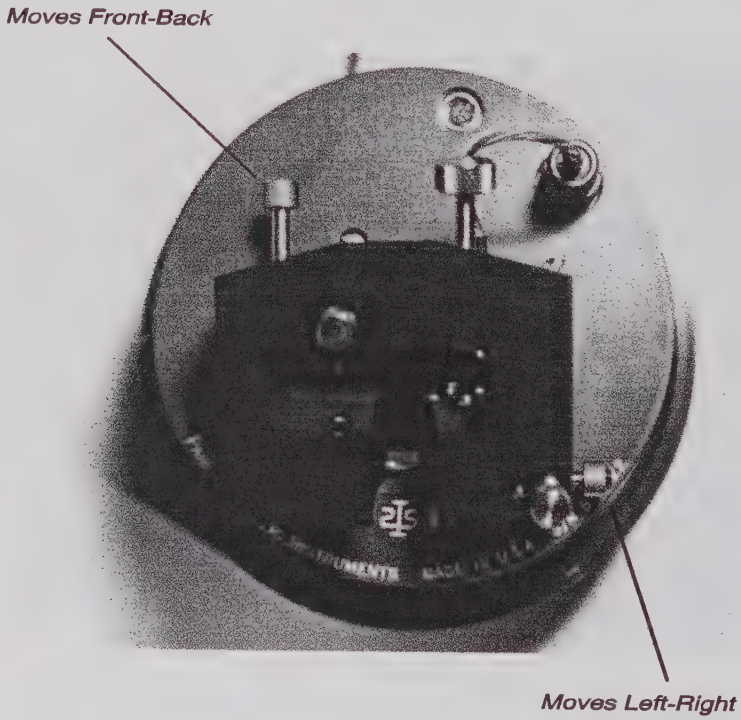


Fig. 2-14 Translation Stage Positioning Screws

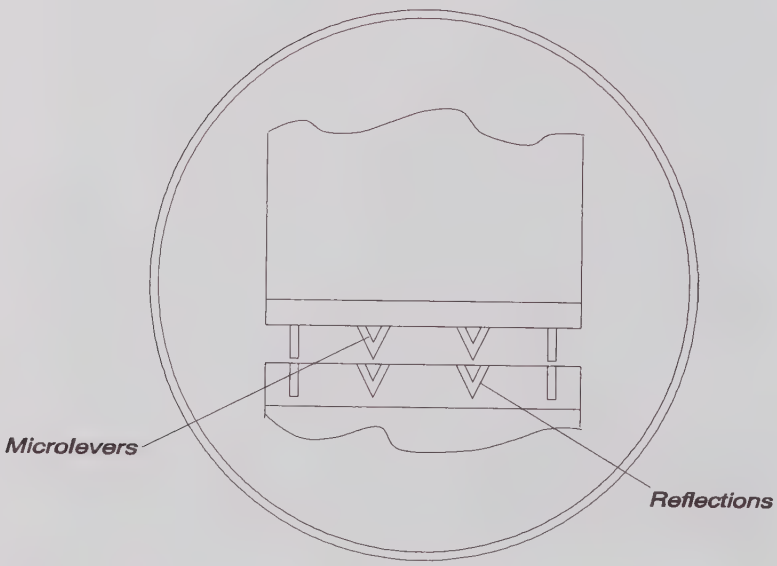


Fig. 2-15 Microlevers and their Reflections

Turn the thumb screws to lower the head toward the sample.
Use the stepper motor if necessary to lower the back of the head.

Lower the head until the Microlevers almost touch their reflections.
Check that the chip and its reflection are parallel (i.e. the chip is parallel to the sample).

2.6.5 Zeroing A-B

(Refer to Section 4.5 for more details.)

Set the BEAM MONITOR METER on the SFM Control Module to A-B.
Set the FORCE MULTIPLIER to 10.
Turn the detector-positioning screw in the SFM head until A-B is zero.

Fig. 2-16 Detector-Positioning Screw

Put the cover on the base.

2.6.6 Performing a Computer Approach

(Refer to Section 4.6 for more details.)

On the SFM Control Module:

Set THE METER switch to ERROR.
Set THE FORCE SETTING knob to zero.
Set the FORCE MULTIPLIER switch to 10.
Turn the NULL knob until THE meter reads zero.
Toggle the FORCE switch up.
Set the FORCE SETTING knob to 5.
Check that the meter needle is deflected to the left.

Set the Z-FEEDBACK GAIN to minimum.
Set the DC LEVEL to TRACK.
Set the SLOW FEEDBACK to COMP.

On the CCU:

Set the X0 AXIS and Y0 AXIS SCAN SIZE knobs to 0.
Set the X AXIS and Y AXIS X10 DC OFFSETs to 5.
Set the COMP/MAN switch to COMP.

On the Computer:

In the Shell Program, select SPM Data Acq.
Find the trace on the scope.
Turn up the SCOPE GAIN.
Select Move Sample.
Select Auto Approach.
When asked to set the MULTIPLIER and GAIN, type <Return>.

2.6.7 Activating Feedback

(Refer to Section 4.6.4 for more details.)

Wait for the computer approach to finish.
Set the TIME CONSTANT on the SFM Control Module to 1.
Set the FAST FEEDBACK GAIN to 1.
Set the DC LEVEL to TRACK.
Switch the SLOW FEEDBACK to AUTO.

2.6.8 Taking an Image

On the computer:

(Refer to 5.1.1 for more details.)

Select Exit and then select Set-Up.
Select the X Scan Rate option.
When prompted, type 4 and press <Return> to change the scan rate.
Set the piezo sensitivity approximately, depending on the scanner.

Scanner	Z	X,Y
2.5 μ	40	60
10 μ	80	240

On the SFM Control Module:

(Refer to 5.2.1 for more details.)

Set the SOURCE to Z.
Set the IMAGE ACQUISITION GAIN to 1.

On the CCU:

(Refer to Sections 5.2.2 and 5.3.2 for more details.)

Set the SCOPE MONITOR switch to IMAGE DATA.

Turn up the scope gain.
Set the SCAN SIZE MULTIPLIER to 100.
Set the Y SLOPE to 0.
Set the ROTATION to 0.
Set the X0 AXIS and Y0 AXIS SCAN SIZES to 9.5 for a 2.5 μ scanner, or 4 for a 10 μ scanner.
Rotate the X SLOPE until the trace is horizontal.

On the computer:

(Refer to Section 8.5 for more details.)

Exit the Set-up menu to the Main Level.
Select Take Data.
Select Take Image.
Select Display Options.
Select Display Amplitude and set it to 1000,0.
The image should look like that shown in Fig. 2-17.

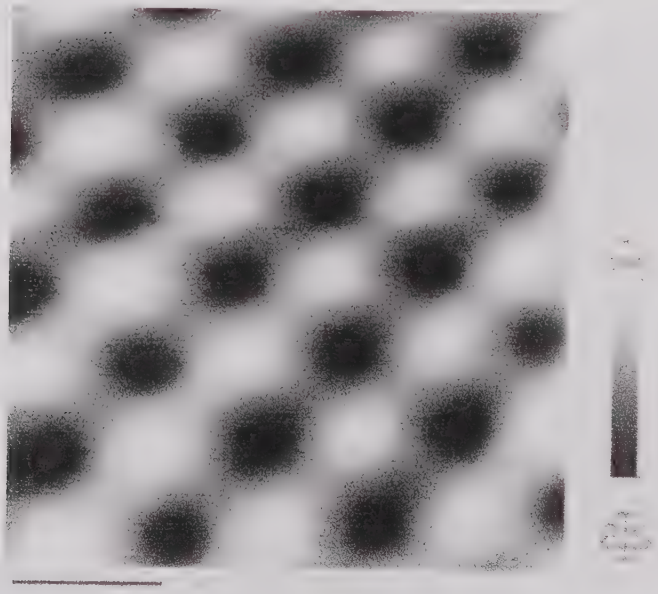


Fig. 2-17 SFM Image of Grating

2.6.9 Shutdown

Set the SLOW FEEDBACK to WDRW.
Set the X0 and Y0 SCAN SIZES to 0.
Set the SAMPLE APPROACH to MAN.
Use the BWD switch to back up 400 steps.
Turn off the power on the CCU.
Reduce the brightness of the monitor.

Appendix 2A Optional 1000X Optical Microscope

Assemble the Baseplate, support post, translation stage, and support post C-clamp.

+ Unpack the baseplate and support post
+ Attach the support post to the baseplate with four 1/4-20x1" screws
+ Unpack the support post C-clamp
+ Slide the C-clamp over the support post, 17 cm from the top.
+ Attach the C-clamp to the support post using one 1/4-20x3/4" screw

Caution: Attach the C-clamp very securely or else the microscope may fall down.

+ Unpack the translation stage
+ Slide the top of the stage to the right and screw in a 1/4-20x3/4" screw
+ Turn the front micrometer to 0 and screw in one 1/4-20x3/4" screw

The set-up should look like that shown in Fig. 2A-1.

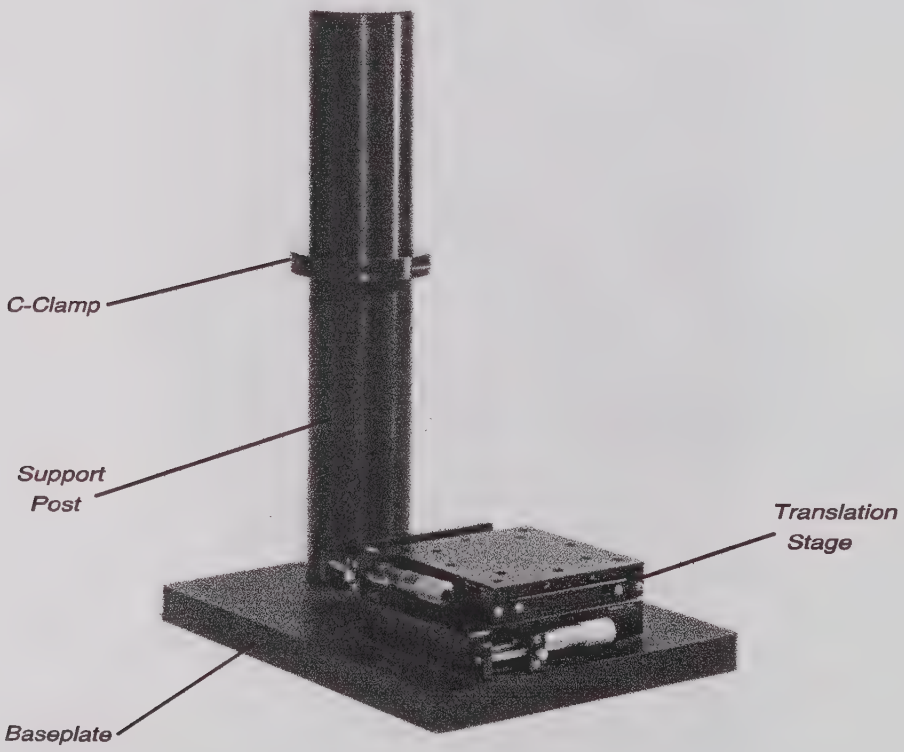
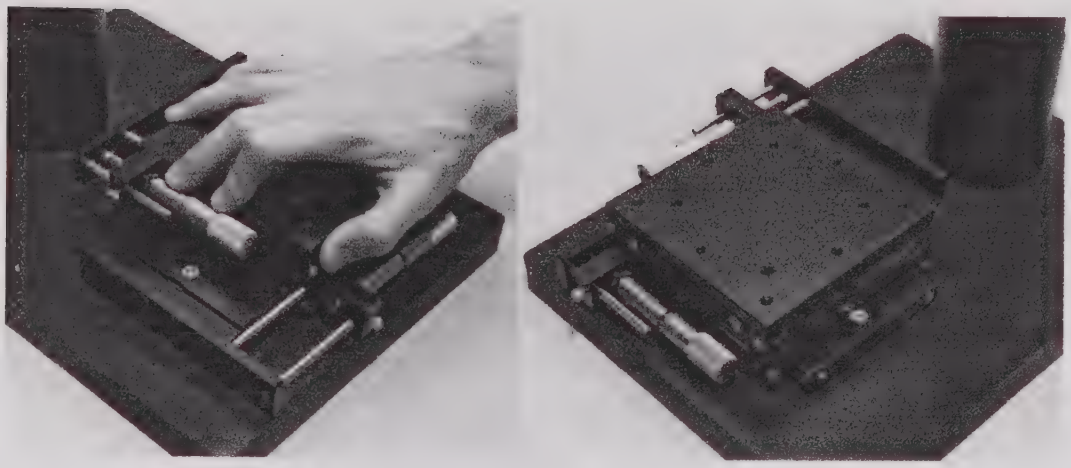


Fig. 2A-1 Baseplate-Support Post Set-Up



2A-2 Attaching Translation Stage to Baseplate

Assemble the microscope head and microscope head C-clamp.

+ Unpack the microscope head and microscope head C-clamp
+ Assemble with five 4mm x 16mm screws
+ Lower this onto the support post, resting on the support post C-clamp

If you want to prevent the microscope from rotating, put three 1/4-20x1/2" screws into the microscope head C-clamp.

Unpack the eyepieces and install them.

Unpack the objectives and screw them into the turret.

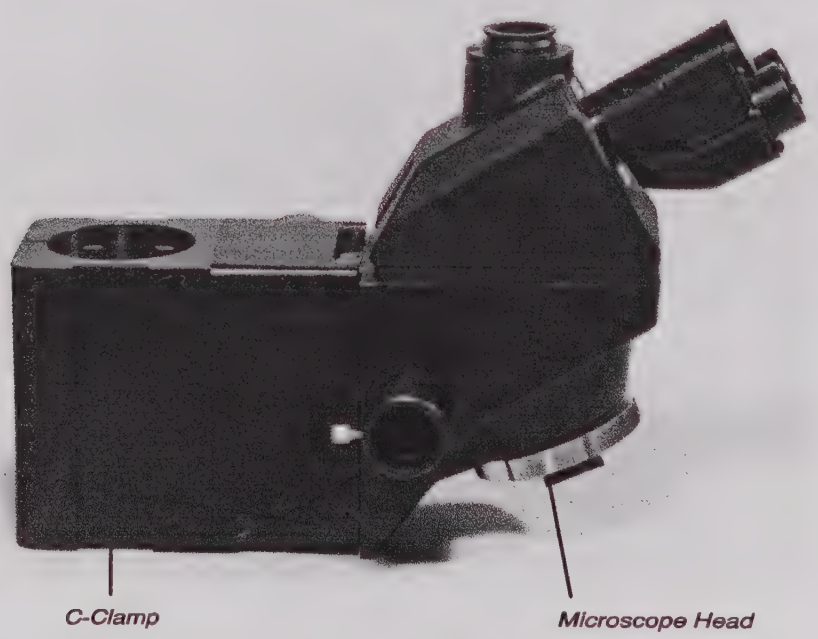


Fig. 2A-3 Microscope Head and C-Clamp

Assemble the Light source, fiber light pipe, and fiber light pipe adapter.

+ Unpack the light source and fiber light pipe
+ Insert one end of the fiber light pipe into the opening in the light source
+ Tighten the screw to hold the light pipe in place
+ Unpack the fiber light pipe adapter
+ Put the wide end of the adapter over the free end of the fiber light pipe
+ Insert the other end of the adapter into the left side of the microscope head
+ Secure the fiber light pipe and adapter in the microscope head
+ Turn on the light source

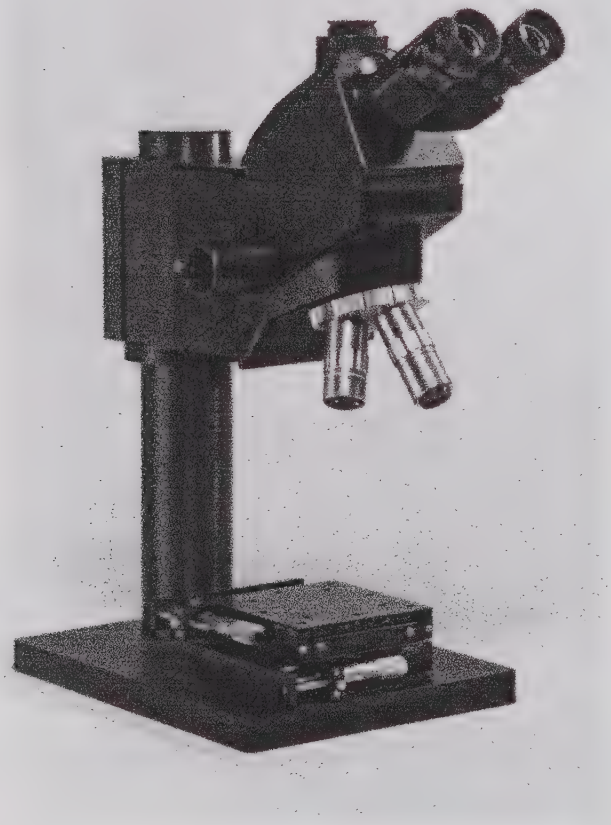


Fig. 2A-4 Assembled Microscope

If you have the video option, unpack it and set it up.

+ Unpack the camera and camera adapter
+ Remove the protective cover from the camera
+ Screw the camera into the camera adapter
+ Remove the cap on the top of the microscope head
+ Attach the camera adapter and camera on top of the microscope head
+ Secure them with the screw on the camera adapter
+ Unpack the power pack and power pack cable
+ Connect the black wire of the cable to negative on the power pack
+ Connect the red wire of the cable to positive on the power pack
+ Connect the cable to the POWER/EXT SYNC plug on the camera

+ Plug in the power pack
+ Unpack the monitor and plug it in
+ Unpack the coax cable
+ Connect one end of the cable to VIDEO IN on the monitor
+ Connect the other end of the cable to VIDEO OUT on the camera
+ Pull down the front panel of the monitor and turn it on

Appendix 2B Computer Start-Up Troubleshooting

When you turn on the computer, hard disk drive, and monitor the computer should automatically boot up the Shell Program (AUTOST).

If the computer fails to load **BASIC**, check that the HPIB cables and power cord are connected properly. If problems persist, call PSI.

If the computer loads BASIC but does not load the **Shell Program** (the PSI screen does not appear), load that program from the floppy disk provided. (It will list "AUTOST" on its label.) To do so, insert the disk in the floppy drive and type `LOAD "AUTOST:,700,1"` and press <Return>. Once the program is loaded, type `RUN` and press <Return>. (Refer to the HP manuals for more details on loading and running programs.) Upon reaching the PSI screen, select File Manager. Type :,700,0,0 and then Select File to see what programs are on the hard disk drive. It should include the following seven programs: SYS_B60, KEY, AUTOST, SPM*_*, IP*_*, STM_CONFIG, and PSI_VER. If some of those files are not on the hard disk drive, they can be copied from the floppy disks. Select Change Disk Add and type :,700,1 to change the disk drive address to the floppy disk. Then choose Select File to see what programs are on the floppy disk--the PSI system disk should be in the drive. Select Copy to copy programs, and when prompted ask to copy files individually (press I and then <Return>). Copy the programs that are missing on the hard disk drive. Then exit from the File Manager menu to the Main Menu.

If the Data Acquisition program, Image Processing program, or any other program is damaged, load it from the floppy disk. (See the above instructions for doing so.)

3 Preparing the Microscope for STM

Setting Up the Microscope

Manual Approach

Computer Approach

To get the best possible images, give careful consideration to the operating environment. Mechanical, acoustical, and electrical noise must be as low as possible; a basement room would be ideal. An accelerometer can be used to make sure the room is vibration-free. The room should be acoustically shielded, if possible, and should not have noisy ventilation. The microscope should be set on a separate surface from the CCU and modules. A solid, heavy table provides reasonable vibration isolation, but an air table or other good vibration isolation is recommended for atomic-scale work.

Tutorial: If this is your first time using the instrument, it is a good idea to follow the tutorial. The tutorial is comprised of a series of boxed instructions and brief exercises that assume the use of a known sample, which is included with the instrument. It is a good way to familiarize yourself with the instrument.

3.1 Setting up the Microscope

Set the base on its prepared table, and, with the power off, connect the base to the CCU with a 25-pin interface cable. Connect to the port on the CCU labeled "STM/SFM Head."

Insert the sample on its stub into the sample holder in the base. Refer to Appendix 3B on sample preparation for STM.

If you are using the tutorial, use the gold calibration grating as your sample.

Caution: When mounting the stub into the sample holder, the set screw should be only finger tight to avoid breaking the delicate scanner. The sample holder is attached to the scanner, which is a piezoelectric tube.

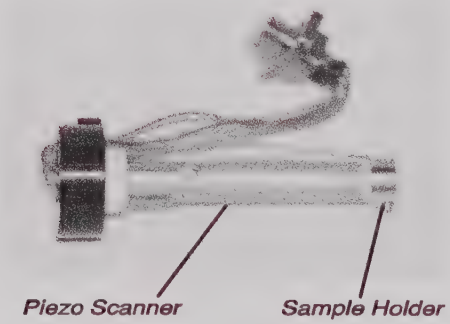


Fig. 3-1 Piezo Scanner and Sample Holder

Gently tighten the set screw with the allen wrench provided in the tool kit.

Warning: Be aware that the piezo scanner carries high voltage, although the sample stub is well insulated from this voltage.

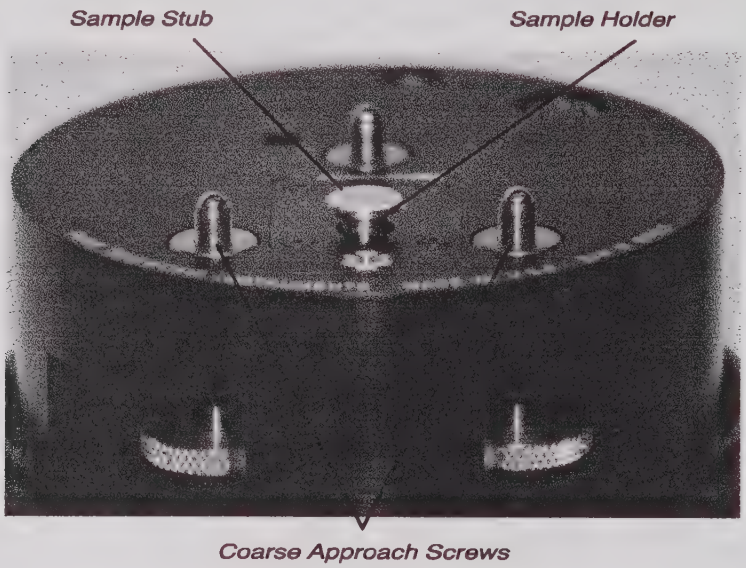


Fig. 3-2 Sample Stub in Sample Holder

Attach the translation stage to the STM head if it is not already on. The translation stage may have to be removed from the SFM head. There are four bolts on the bottom of the translation stage and can be removed with one of the allen wrenches provided.

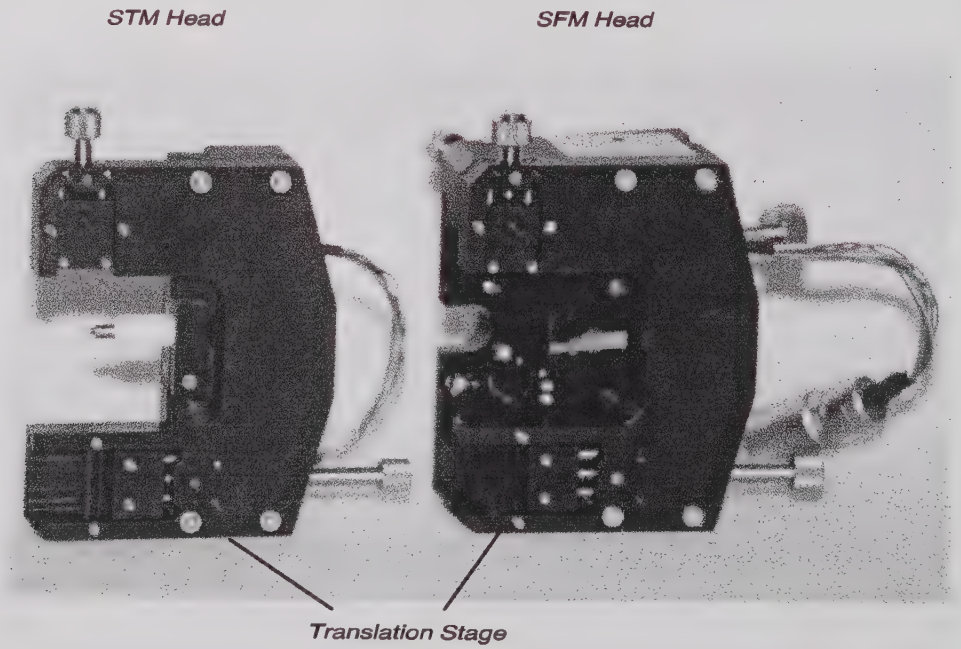


Fig. 3-3 Translation Stage on STM and SFM Heads

Plug the 12-pin connector of the STM head into the base, making sure it clicks in, and stand the head on its side on the base.

Prepare a new STM tip if needed. Using a damaged or oxidized tip is not recommended. Refer to Appendix 3A for instructions on tip preparation.

The quality of the tip is essential to getting good STM images. Try a variety of tips to see which work best for the sample. Be aware that tungsten tips oxidize quickly and should be made immediately before use. PtIr tips are poorly defined and may cause multiple tip imaging, but are less prone to oxidation.

Insert the blunt end of the STM tip into the hole in the tip holder on the head, and tighten the set screw. Do this with the head standing on its side. Use a pair of tweezers or needle-nosed pliers and the allen wrench. For most purposes, the tip can be positioned so that it is flush with the plane of the translation stage.

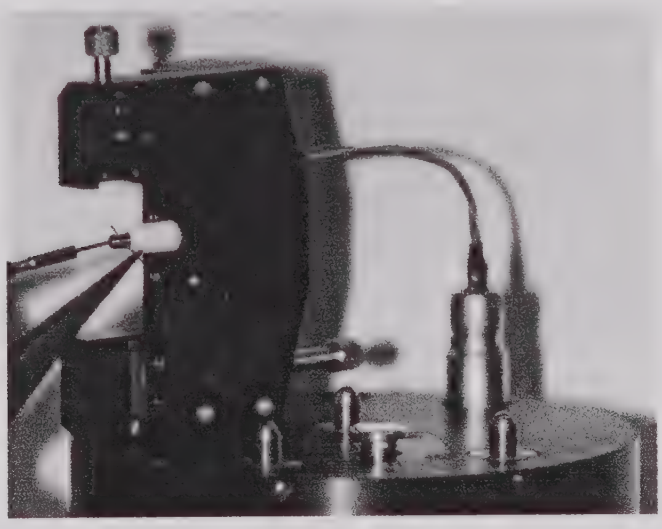


Fig. 3-4 Putting Tip in STM Tip Holder

The tip can be rotated by loosening the screw on the base of the tip holder as shown in Fig. 3-5. If you are using the optional 1000X optical microscope, the tip will need to be rotated about 45 degrees.

Raise the coarse-approach screws on the base so that when the head is resting on them, the tip will not hit the sample.

Set the head on the approach screws, being careful not to let the tip touch the sample. (The sample should already be in place.) An easy way to position the head is to first position the cone (right side) on to the right coarse approach screw, tilt the head down so that the flat (back) makes contact with the fine approach screw, and then carefully lower the slot (left side) onto the left coarse approach screw, watching to make sure the tip does not hit the surface. If the tip hits the sample, start over. It is ruined by contact.

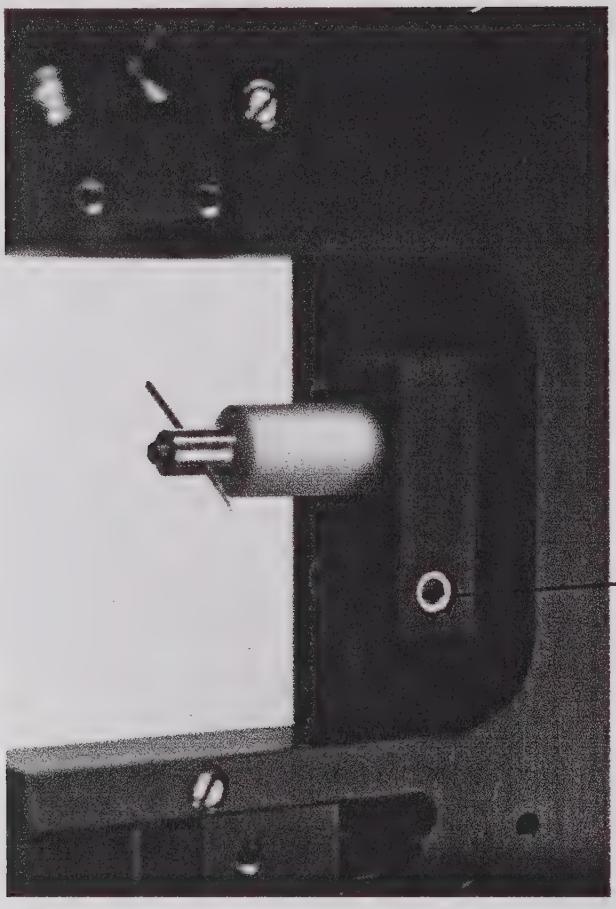


Fig. 3-5 Rotating the Tip

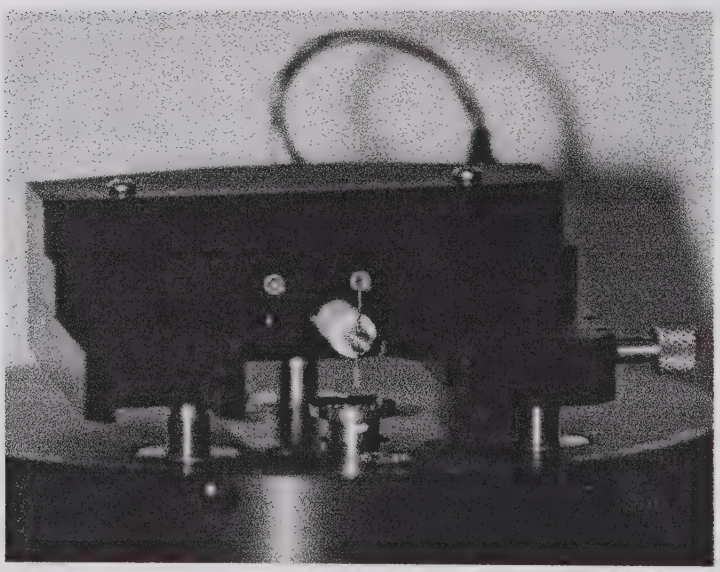


Fig. 3-6 The STM Head on the Base

3.2 Manual Approach

Set up the 120x optical microscope and fiberoptic lightsource in front of the STM, and look at the tip and sample. Begin with the magnification reduced by twisting the zoom at the front (objective end) of the optical microscope. Adjust the lightsource so that the sample and tip can be seen clearly.

Adjust the position of the tip using the translation-stage positioning screws until it is over the desired area of the sample. The right knob moves the cone, moving the head left-right. The back knob moves the slot, moving the head front-back.

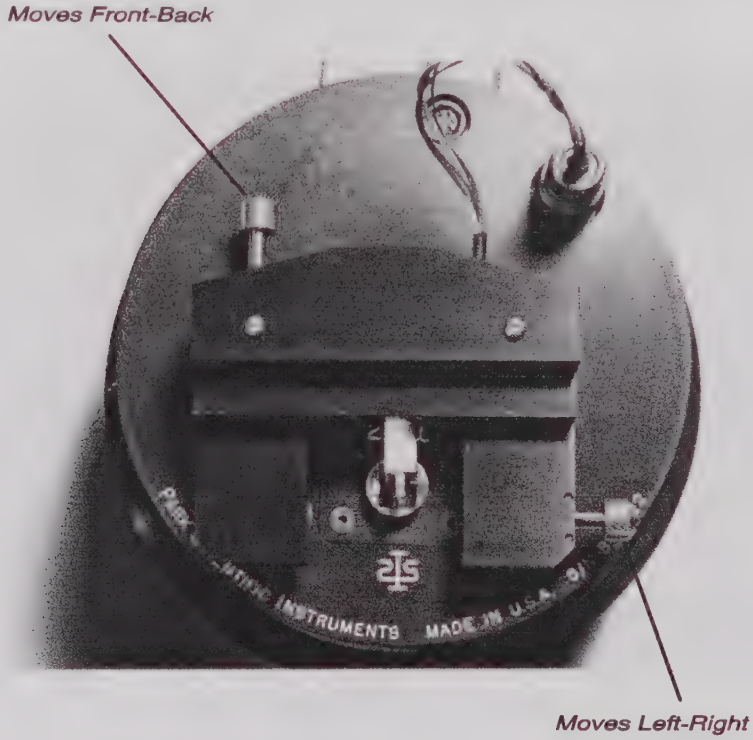


Fig. 3-7 Translation-Stage Positioning Screws

Start to lower the head and tip toward the sample using the two coarse-approach screws.

If necessary, use the stepper motor to raise or lower the back of the head to keep it roughly parallel to the base. (This is not critical with STM.) The motor is controlled with the FWD/BWD switch on the SAMPLE APPROACH panel of the CCU when the COMP/MAN switch is set to MAN.

Watch the tip approach its reflection, or its shadow if the sample is not reflecting.

Lower the tip with the coarse-approach screws until it is as close to the surface as possible without touching. Position the light for the clearest possible visibility. It is helpful to maximize the optical magnification by using the zoom on the end of the objective of the optical microscope. The farther away the automatic approach is begun, the longer it will take; estimating these distances becomes easier with practice. Remember that if the tip touches the sample, a new tip must be put in.

Put the cover on the microscope. The microscope is ready for a computer approach.

3.3 Computer Approach

For a computer approach, the control electronics and computer should be set up as described in Chapter 2. The CCU should be connected to the hard disk drive with the 4m HPIB cable and should be plugged into the power strip. The STM should be set up as described in 3.1, and the base should be connected to the CCU with a 25-pin interface cable.

3.3.1 On the STM Control Module:

Connect the STM Control Module to the CCU with a 25-pin interface cable. It is convenient to put the Control Module on top of the CCU.

Set the tunneling current with the potentiometer and order-of-magnitude toggle switch on the TUNNELING panel of the STM Control Module. For good conductors, use a high current setting (e.g. 1 nA for gold or graphite). For poor conductors, a lower value is appropriate. If the set current is too high, the tip will crash into the sample.

If you are using the tutorial, set the current to1 nA.

Set the bias-voltage in the same way. Poorer conductors require higher bias-voltages. 0.1 V or 0.2 V is appropriate for gold; 5 V may be appropriate for semi-conductors. The sign of the bias-voltage can be changed in the software as described in Section 10.1.1.

If you are using the tutorial, set the voltage to 0.2 V.

Set the FAST FEEDBACK GAIN on the Z FEEDBACK panel to minimum.

Set the SLOW FEEDBACK switch on the Z FEEDBACK panel to COMP. This switches the control of the Z-piezo to the computer.

Set DC LEVEL to TRACK. Otherwise, the signal read by the computer will be DC-blocked.

Ignore the other functions on the Control Module for now.

3.3.2 On the Central Control Unit:

Turn ON the power on the CCU. The power switch on the STM Control Module is for UHV use only.

Set the X0 AXIS and Y0 AXIS SCAN SIZEs to zero on the SCAN CONTROL panel. Otherwise, the sample will be scanning and the tip may crash during approach.

Set the X and Y DC OFFSETS to 5 on the X10 scale on the SCAN CONTROL panel. The tip will be centered in the piezo range.

Set the COMP/MAN switch on the SAMPLE APPROACH panel to COMP. Then the computer will control the stepper motor.

Ignore the other functions on the CCU for now.

3.3.3 On the computer:

Run the Data Acquisition program from the Shell Program by pushing the softkey labelled SPM Data Acq. to initialize a scan on the electronics.

Find the trace on the scope using the scope control knobs.

The tip bias-voltage polarity can be set using the SPM Mode option of the Set-up menu in the Data Acquisition program. To change it, choose a mode and input the bias sign (tip relative to sample).

Select Move Sample in the main level of the DATA ACQUISITION program. This menu allows computer control of the stepper motor in the base.

Select Auto Approach. The computer will control the stepper motor and the Z feedback for a crashless approach.

Hit <Return> to select the default number of steps between piezo scans, 10.

If you are using the tutorial, watch the Z piezo on the SCANNER MONITOR panel and the STEP COUNTER on the CCU during computer approach. The computer will direct the stepper motor to move ten steps while the Z piezo is withdrawn. The piezo is then extended, and if no tunneling current is detected, it is withdrawn again and the stepper motor moves again. Eventually a current will be detected and the approach will stop.

3.3.4 Activating Feedback

Wait for the computer approach to finish. If it takes too long, check that the COMP/MAN switch is toggled to COMP. You may want to select Exit on the computer to stop the approach and lower the head some more manually. Be aware that it is possible to run out of range on the fine approach screw. If this happens, back up the stepper motor and lower the head further with the coarse approach screws.

Turn the TIME CONSTANT on the Z FEEDBACK panel of the STM Control Module up to around 5, to prevent oscillation. This is the time constant of the feedback loop and will be optimized later.

Set the GAIN on the Z FEEDBACK panel to around 1, to turn on feedback. This is the gain of the feedback loop and will be optimized later.

Toggle the SCOPE MONITOR switch on the CCU up to look at the DETECTOR SIGNAL (the output of the preamp).

Turn the SCANNER MONITOR switch to Z to look at the position of the Z piezo.

Switch the SLOW FEEDBACK to AUTO on the Z FEEDBACK panel of the STM Control Module. The piezo will extend until the set tunneling current is detected.

Check that the z piezo extends about halfway on the SCANNER MONITOR and stops. If the piezo keeps extending and does not stop, the approach failed. This may be due to preamp noise; run the Auto Approach again.

Check that a tunneling current appears on the scope of the CCU. The trace on the scope should rise (if the bias-voltage polarity is positive) until the current reaches the value set on the STM Control Module. If the tunneling current appears to be pegged, it may be because the tip is touching the sample.

If the TUNNELING current looks noisy, adjust the bias-voltage and TUNNELING current.

Note: Toggling the CURRENT and VOLTAGE order-of-magnitude switches are changes too abrupt for feedback to respond adequately. To protect the tip, withdraw the tip with the SLOW FEEDBACK switch before toggling them.

If the Z piezo is far from the center of its range, use the approach stepper motor to lower the head toward the sample or raise it away from the sample. When the piezo is not near the center of its range, it may run out of range during scanning if the sample is tilted or very rough. FWD moves the tip towards the sample, and BWD moves it away, when the COMP/MAN switch is set to MAN. Move about ten steps at a time. If the Z piezo is extended too far (the right side of the bar graph is lit) move the tip toward the sample.

Note: To protect the tip, withdraw the sample with the SLOW FEEDBACK switch before using the stepper motor.

Appendix 3A Preparing STM Tips

A new STM tip must be prepared when starting or when the tip being used is damaged or oxidized. This can be done in several ways. When using a sample with features of high aspect ratio, make etched tips, since cut PtIr tips will cause tip imaging. When using the optional 1000X optical microscope, make etched tips as they can be angled to allow viewing of the tip-sample region from above.

Reasonably good tips can be made by cutting PtIr wire at 45 degrees with sharp wire cutters. (See Fig. 3A-1.) Hold one end of the wire in a vice or with a pair of pliers. Pull the other end with wire cutters and cut the wire cleanly and quickly. The tips do not look sharp, but actually they are. These tips do not oxidize quickly and may be kept for a long time. However, their overall shape is not well defined and can cause multiple tip imaging.

Tips can also be etched from tungsten wire.

If you have a tip etcher, unpack it.

+ Unpack the tip etcher electronics
+ Unpack the beaker
+ Unpack the carbon electrode and tip electrode
+ Unpack the cables
+ Unpack the KOH
+ Unpack the tungsten wire

Fig. 3A-1 Making PtIr tips

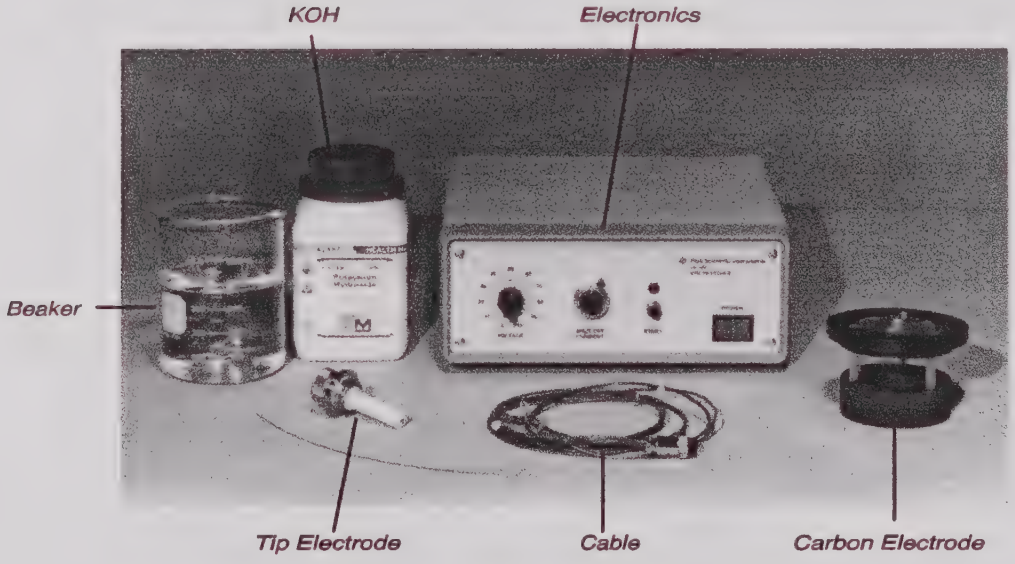


Fig. 3A-2 Components of the Tip Etcher

Set up the tip etcher.

+ Connect the power cord to the electronics and plug it in
+ Set the carbon electrode into the beaker
+ Put the tip electrode into the top of the carbon electrode
+ Connect the cable between the carbon electrode and the electronics

Warning: Wear rubber gloves and goggles whenever working with KOH.

Fill the beaker with 50 ml of KOH pellets, and add de-ionized water to make 375 ml of solution.

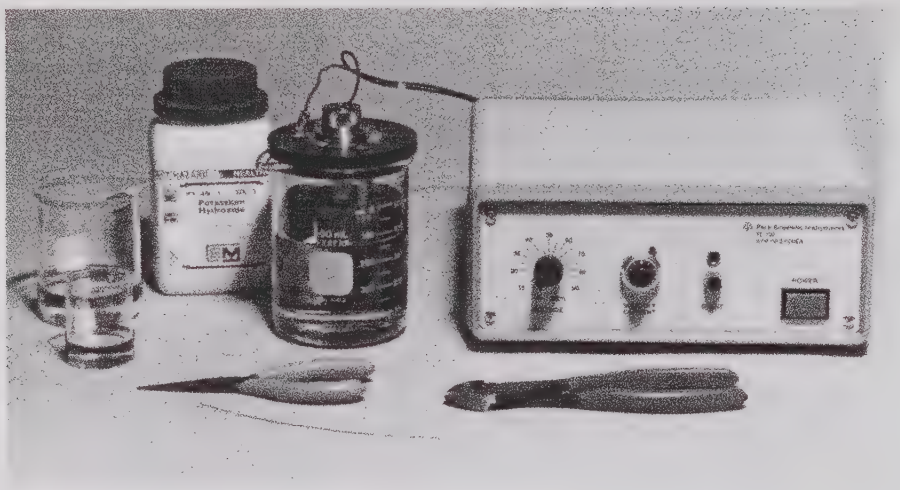


Fig. 3A-3 Set Up Tip Etcher

Stir the solution with a glass stirring rod.

Insert a 1" length of 20 mil tungsten wire into the end of the tip electrode. Use strong wire cutters to cut the tungsten wire as ordinary wire cutters will be destroyed.

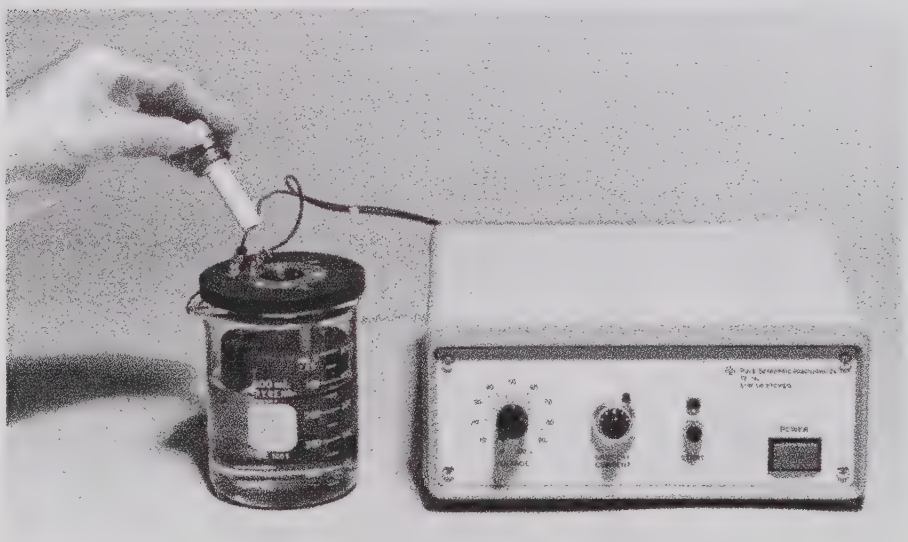


Fig. 3A-4 Etching a Tungsten Tip

Push the center electrode all the way into the lid. There should be at least 1 cm of wire above the solution.

Set the voltage on the tip etcher electronics to 80% and the shut-off current to 0.5, turn on the power and flip the toggle switch to start etching. You will see tiny bubbles surround the immersed portion of the wire. After a few minutes the power will shut off, when the current reaches the shut-off value. The tip should extend about 0.5 to 1 mm below the surface of the solution. You

should experiment with different voltages and shut-off currents to make the best tips; Fig. 3A-5 shows a good tip shape.

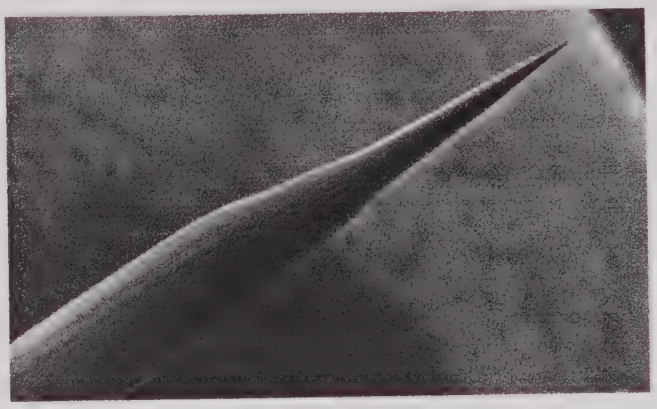


Fig. 3A-5 Good STM Tip Shape

Remove the tip electrode (it is a press fit) and remove the tip with needle-nosed pliers.

Rinse the tip in de-ionized water and then isopropyl alcohol. These tips will oxidize and should not be kept longer than 1-2 days. Because of their shape they are appropriate for use with high-aspect-ratio features. They may also be angled relative to the surface for samples with low aspect-ratio features for use with the optional 1000X optical microscope.

Appendix 3B Preparing STM Samples

The sample must be attached to a sample stub that will fit into the top of the scanner. The largest sample size is about 1" by 1" x .5" high. The stubs provided are standard SEM stubs and can be ordered from PSI or from SEM supply houses directly. For STM, the sample must be conducting, and the surface of the sample must make electrical contact with the bottom post of the sample stub. This can be done in several ways.

One possibility is using silver epoxy and a standard SEM stub. If the sample is conducting throughout, sticking it on an SEM stub with silver epoxy is sufficient. If only the surface is conducting, the silver epoxy must extend from the sample stub to the surface.

Fig. 3B-1 Special Sample Holders

Another possibility, also useful when the whole sample is not conducting, is to use metal clips to make contact with the sample surface. Some special sample holders with conducting clips are available from PSI. Some clip arrangements are shown in Fig. 3B-1.

Take care in making the sample's surface as level as possible. Leveling the sample at the start will minimize the need for electronic tilt correction.

Clean the sample as desired. Compressed air can be used to blow off dust.

Appendix 3C Using the 1000X Optical Microscope

The optical microscope should be set up as described in Appendix 2A.

Put the STM head and base on the translation stage of the optical microscope. The optical-microscope head should be rotated out of the way.

Rotate the optical microscope head back over the STM head. Use the focus knobs to make sure the objectives are raised high enough to ensure that they will not hit the STM head.

Use the 10X objective first.

Turn on the light source and center the spot from the objective on the tip-sample region.

Focus the optical microscope until the sample is in view. The large translation stage allows you to find the desired feature to be imaged.

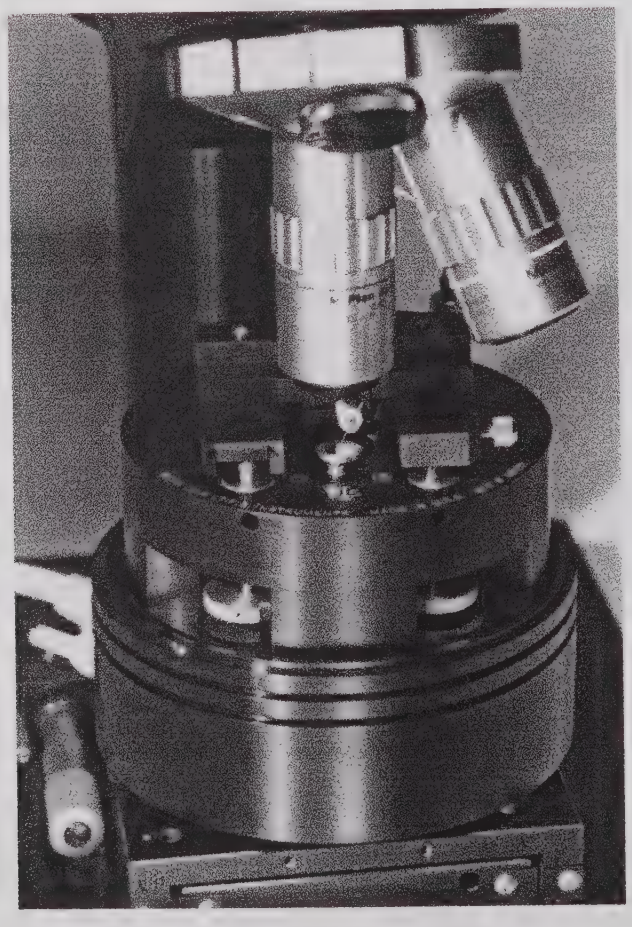


Fig. 3C-1 1000X Optical Microscope with STM

Use the translation stage on the STM head to bring the tip to the desired feature.

The STM can be operated with the optical microscope on and the cover off, but this may introduce some 60-Hz noise. For rough surfaces (1000 Å peak-to-valley) this should not be noticeable, but for smooth surfaces the optical microscope should be rotated out of the way and the cover should be put on the STM.

All three objectives (10X, 20X and 50X) can be used, but when using the 50X lens make sure that the lens does not hit the STM body and that the STM tip length does not interfere with the objective. If this is a problem, cut the back end off the tip and pull the tip holder out far enough for the objective to clear the head.

4 Preparing the Microscope for SFM

Installing the Chip in the Head
Setting Up the Microscope
Positioning the Laser
Manual Approach
Zeroing A-B
Computer Approach

Warning: Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous laser light exposure.

Do not turn on the laser power yet.

To get the best possible images, give careful consideration to the operating environment. Mechanical, acoustical, and electrical noise must be as low as possible. A basement room would be ideal. An accelerometer can be used to make sure the room is vibration-free. Consult PSI for quantified acceptable noise. The room should be acoustically shielded, if possible, and should have no noisy ventilation. The microscope should be set on a separate surface from the electronics. A solid, heavy table provides reasonable vibration isolation, but an air table or other good vibration isolation is required for atomic-level imaging.

Tutorial: If this is your first time using the instrument, it is a good idea to follow the tutorial. The tutorial is comprised of a series of boxed instructions and brief exercises that assume the use of a known sample, which is included with the instrument. It is a good way to familiarize yourself with the instrument.

4.1 Installing the Microlever Chip in the Head

If you are using the tutorial, look at the underside of the SFM head to become familiar with its operation. Light from the laser diode is reflected off the steerable mirror onto the Microlever, which is held in the Microlever mount. The light is reflected up into the position-sensitive photodetector (PSPD). Turn the mirror steering screws and PSPD positioning screw to see their effects.

Attach the translation stage to the SFM head if it is not already attached. It may have to be removed from the STM head. Fig. 4-1 shows how the translation stage fits on the SFM and STM heads.

Prepare a new Microlever chip following the instructions in Appendix 4A if the one being used is damaged.

The quality of the SFM image is dependent partly on the quality of the Microlever being used. To get the best possible image, use a new Microlever. When doing less critical work, Microlevers need not be changed between samples. A damaged Microlever is the first thing to suspect when the system does not work well; if there is any reason to suspect that the Microlever is damaged, replace it.

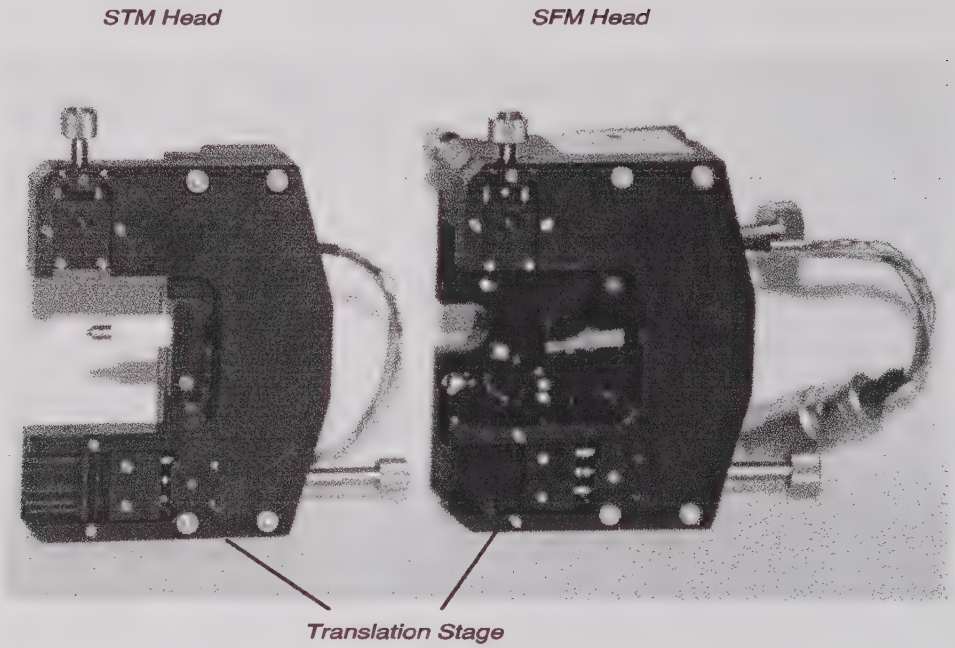


Fig. 4-1 Translation Stage on STM and SFM Heads

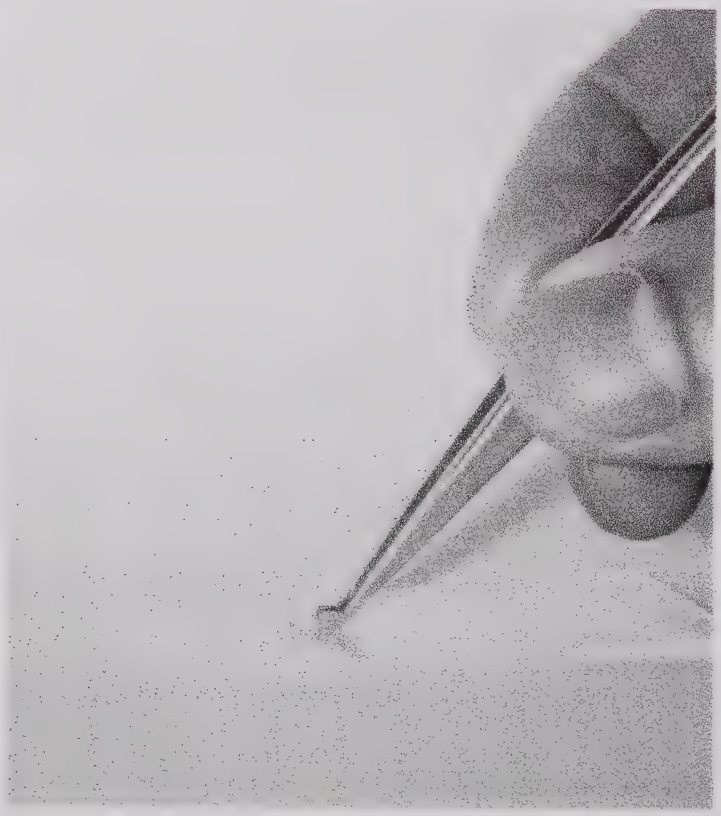


Fig. 4-2 Holding a Microlever Chip

Hold the SFM head in one hand and depress the chip holder spring with the index finger of that hand. This will let you install a Microlever chip. If there is already a Microlever chip in the holder, remove it.

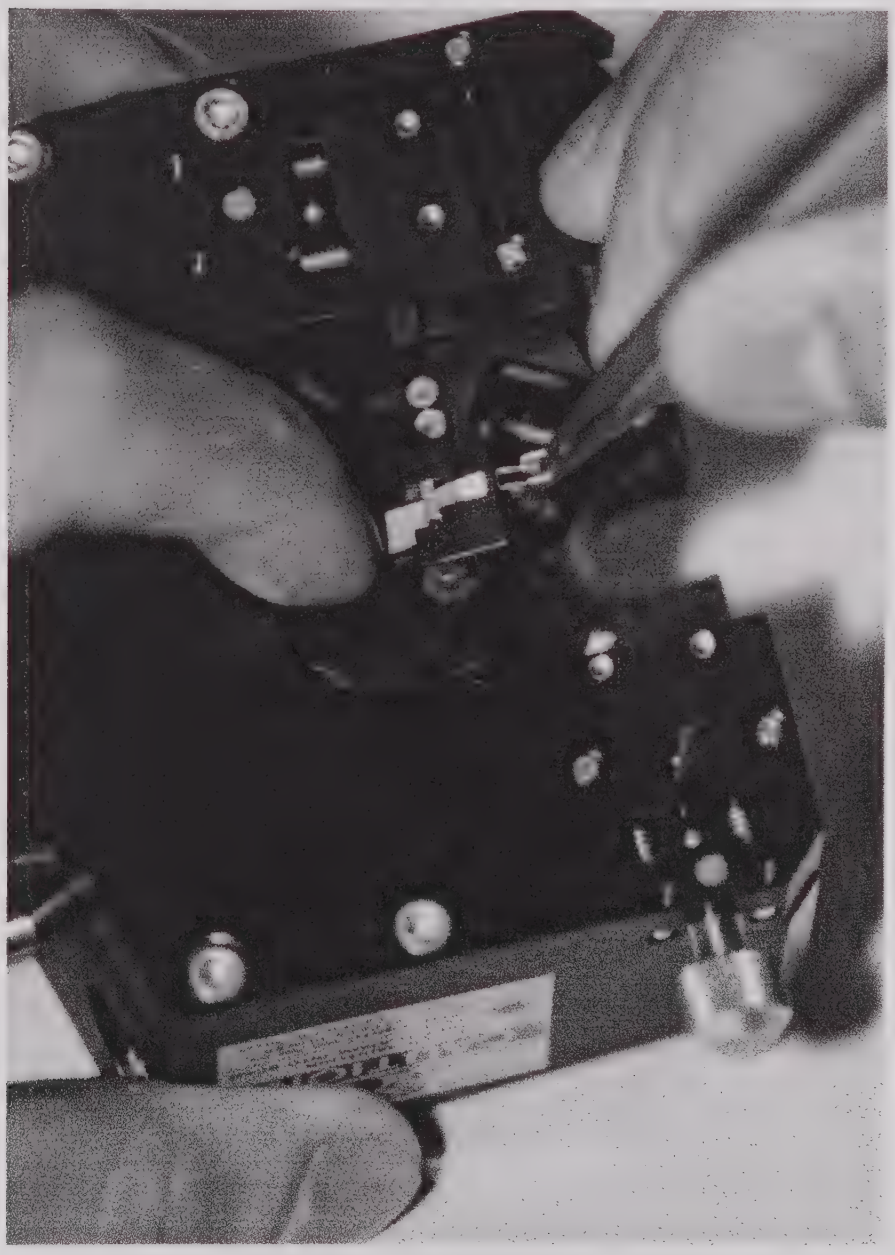


Fig. 4-3 Installing a Microlever Chip

If you are using the tutorial, try installing a spacer in the Microlever mount.

Pick up the Microlever chip with the other hand using the chip-handling tweezers. Hold the chip as shown in Fig. 4-2.

Insert the chip into the clip so that it is flush against the right-angle stop. Slide the chip in all the way and push it from the side so that it hits the stops in the back and on the side. If the chip is not placed flush against the stops, it may not be possible to position the detector so that the laser beam hits the center of the photodetector. When the chip is positioned properly, only minor adjustments of the mirror and detector positions will be necessary.

If the Microlevers are touched at any time, use a new Microlever chip.

If you are doing a system test, go to 2.6.2.

4.2 Setting Up the Microscope

Warning: Do not plug in the 12-pin connector yet. The connector should not be connected until the head is in place to avoid exposure to laser light. Laser power should also be turned off on the SFM Control Module.

Set the base on its prepared table, and, with the power off, connect the base to the CCU with a 25-pin interface cable. Connect to the port on the CCU labeled "STM/SFM Head."

Insert the sample on its stub into the sample holder in the base. Refer to Appendix 4B on sample preparation for SFM.

If you are using the tutorial, use the gold calibration grating as your sample.

Caution: The set screw should only be finger tight to avoid breaking the delicate scanner. The sample holder is attached to the scanner, which is a piezoelectric tube.

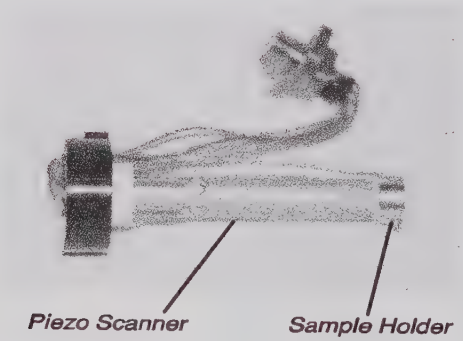


Fig. 4-4 Piezo Scanner and Sample Holder

Gently tighten the set screw with the allen wrench provided in the tool kit.

Warning: Be aware that the piezo carries high voltage, although the sample stub is well insulated from this voltage.

Raise the coarse-approach screws so that when the head is resting on them, the tip will not hit the sample.

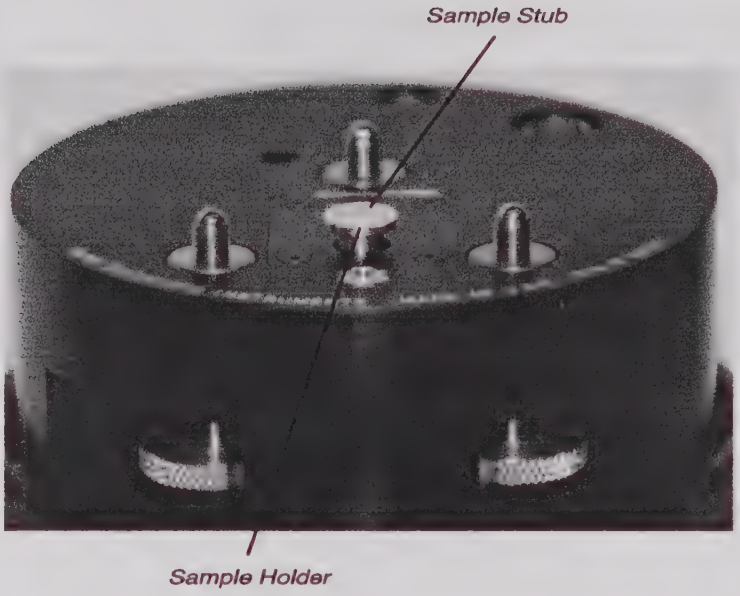


Fig. 4-5 Sample Stub in Sample Holder

Set the head on the approach screws, being careful not to let the tip touch the sample. (The sample should already be in place.) An easy way is to first position the cone (right side) on to the right coarse approach screw, tilt the head down so that the flat (back) makes contact with the fine approach screw, and then carefully lower the slot (left side) onto the left coarse approach screw, watching to make sure the tip does not hit the surface.

Fig. 4-6 SFM Head on the Base

4.3 Positioning the Laser

Connect the CCU to the SFM Control Module with a 25-pin interface cable and check the other connections. The base should already be connected to the CCU with a 25-pin connector. Check that the CCU is plugged in and connected to the computer. Do not turn on the laser power yet.

Caution: Do not plug the 12-pin connector of the SFM head into the base with the laser power turned on. This will reduce the lifetime of the laser.

With everything still turned off, plug the 12-pin connector on the SFM head into the base. Hold onto the head while doing this to keep it from falling off the approach screws.

Turn on the CCU, then turn on the laser at the SFM Control Module. Always do it in that order. The laser beam should be visible when the laser is on.

Set up the 120X optical microscope in front of the microscope, and look at the chip and Microlevers. Set up the light source, and adjust it so the sample and tip can be seen clearly. To locate the chip, it is helpful to reduce the magnification by twisting the zoom at the front (objective end) of the optical microscope.

Use the mirror-steering screws to steer the laser spot until it hits square in the middle of the desired Microlever.

If you are using the tutorial, try positioning the laser spot first onto the back of the Microlever chip without using the 120X optical microscope. This is easier than positioning it onto the Microlever itself and is helpful in locating the laser beam.

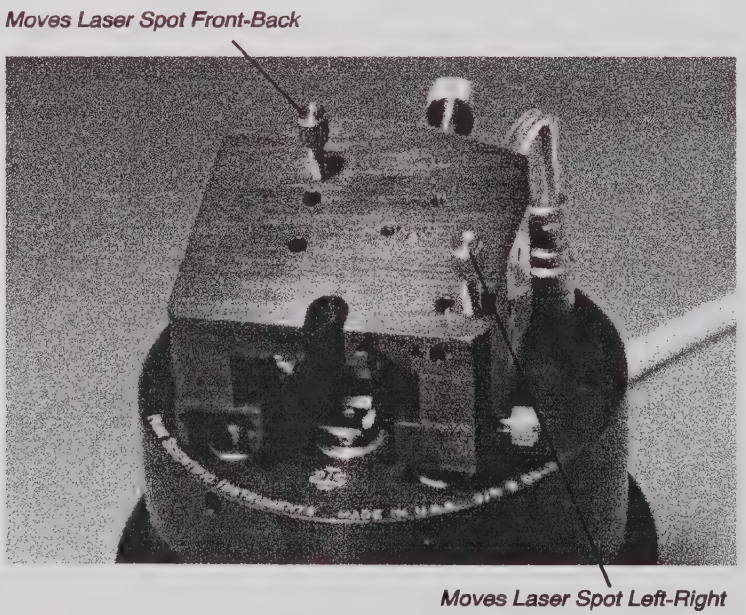


Fig. 4-7 Mirror Steering Screws

You will use only one Microlever, although the others are there. The deflection of adjacent Microlevers will be only very weakly coupled to the deflection of the Microlever being used. Refer to Section 4A.3 for a discussion of which Microlever to use.

The point on the Microlever you are aiming for is indicated in Fig. 4-8. If you are using a V-shaped Microlever, it may be easiest to position the laser spot on the right arm of the Microlever, then move it forward toward the end of the Microlever with the left mirror-steering screw.

Fig. 4-8. Target for Laser Spot

When the mirror is properly positioned, light will scatter equally off the various edges of the Microlever. This is illustrated in Fig. 4-9, with the light spots representing laser light. If the end of the Microlever or one of the edges is brighter than the others, the spot is not centered. The surface of the Microlever should be uniformly illuminated. Some light will hit the surface of the sample, but usually very little light will be reflected from the sample into the detector because the Microlever is tilted by about 15° with respect to the sample surface.

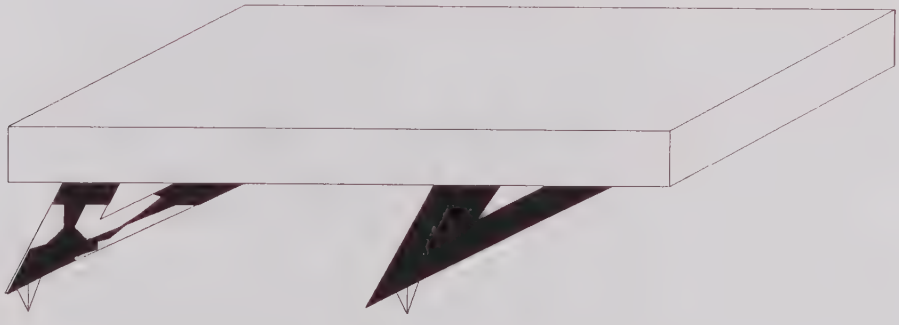


Fig. 4-9 Microlever Appearance When Laser is Correctly Positioned

Set the METER switch on the BEAM MONITOR panel on the SFM Control Module to A+B. This is the sum of the signals from the two halves of the photodetector. When the mirror is properly positioned, nearly all of the light will be reflected off the Microlever and A+B will be maximum.

Make final adjustments to the laser by watching the meter and trying to maximize A+B with the laser positioning knobs. In the beginning, this should be done each time. Afterwards, be sure to look again at the Microlever to see where the light is hitting. If it is far off center, or well up on the Microlever arm, chances are the Microlever is bent and should be discarded.

After aligning by eye, make sure the laser spot is hitting in the middle of the detector. You can easily verify this by putting a small piece of paper in front of the detector and, with the PSPD knob, centering the laser spot on the detector. At this point it should be easy to see a signal when the Beam Monitor is set to A+B.

With experience, all alignment can be done by eye; just check afterwards to see that A+B is reasonably high. (The signal need not be fully maximized for operation.) Remember that A+B will be low if the light does not hit near the center of the detector.

If you are doing a system test, go to 2.6.4.

4.4 Manual Approach

Adjust the position of the tip by moving the translation stage until the tip is over a desired part of the sample. The right knob moves the cone, moving the head left-right. The left moves the slot, moving the head front-back. When doing this be careful that the tip does not hit the sample.

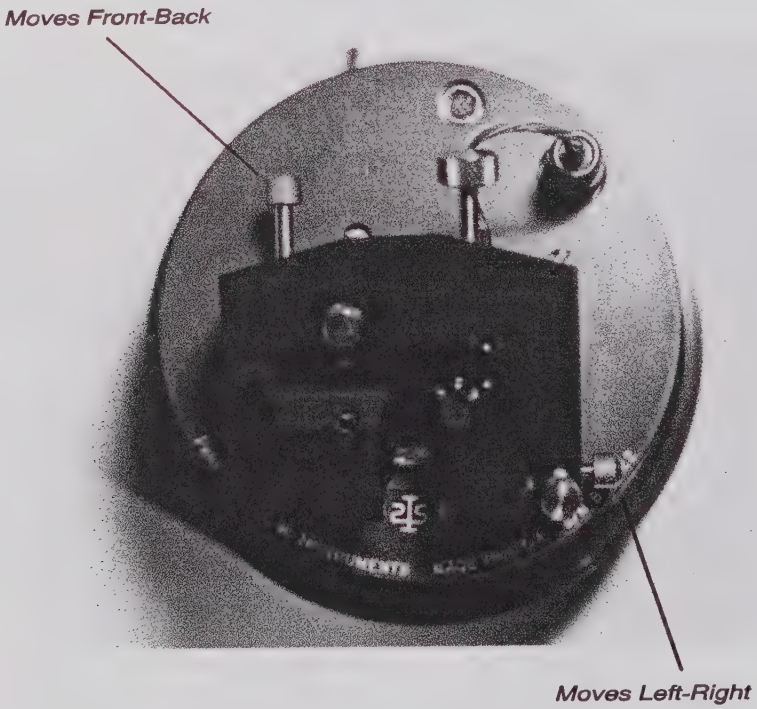


Fig. 4-10 Translation Stage Positioning Screws

Start to lower the head and Microlevers toward the sample using the two coarse-approach screws on the base. You want to lower the tip toward the sample so that it is close enough for a computer approach to take over. The computer will control the third (fine) approach screw.

Use the stepper motor to raise or lower the back of the head to keep it roughly parallel to the base. The motor is controlled with the FWD/BWD switch on the SAMPLE APPROACH panel of the CCU; set the COMP/MAN switch to MAN.

If using a reflecting sample, lower the head until the Microlevers almost touch their reflections, keeping the chip parallel to its reflection. At a close distance, the Microlevers and their reflections should be visible as they approach each other. (See Fig. 4-11.) Adjust the right and left screws so that the chip is parallel to its reflection (and thus to the surface). Otherwise, parts of the chip other than the desired Microlever may touch the sample during approach or scanning. It may help to turn off the laser power on the SFM Control Module while adjusting the coarse-approach screws. If you start from too far away, the computer approach will take a long time and the fine approach screw may even run out of range.

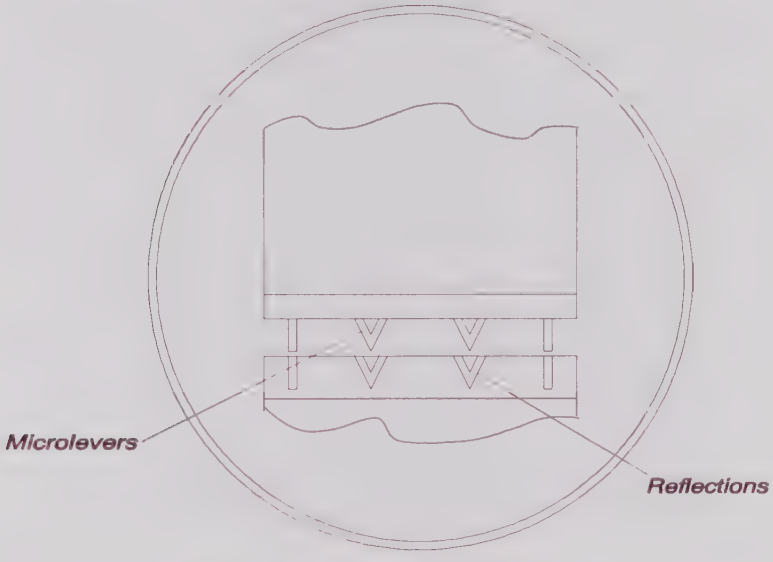


Fig. 4-11 Microlevers and Their Reflections

Avoid letting the Microlevers crash into the sample, to protect the tip.

If the surface is not reflecting, use the coarse approach screws to lower the Microlevers until they gently and symmetrically touch the surface, then back off slightly. When they touch the surface, the Microlevers may actually be seen to bend, and the reflection of the light from the surfaces of the Microlevers change. Back off so that the Microlevers are close to, but no longer touching, the sample. The Microlevers are very flexible and can be bent far without breaking when a gentle force is applied.

If you are using the tutorial, bring the Microlevers down until the tips touch the surface, so that you can see the change in the scattered light. Then back up so that they are no longer touching.

4.5 Zeroing A-B

Set the METER switch on the BEAM MONITOR panel on the SFM Control Module to A-B. A-B, which is the important signal for feedback in SFM, is the difference in the laser power reaching the two halves of the position-sensitive photodetector (PSPD). Deflections in the Microlever steer the laser beam across the PSPD, and thus change A-B.

Move the detector in the head in or out until A-B is as near zero as possible with the MULTIPLIER on the FORCE panel set to 10. The Microlever tip should not yet be touching the

sample, hence the Microlever should be undeflected, so you want to center the light exactly on the detector. Then, when the tip touches the surface, and the Microlever is deflected, the light will move off-center.

Fig. 4-12 PSPD Positioning Screw

If you are using the tutorial, hold a small piece of paper in front of the detector to see where the reflected light is hitting. There should be a round spot hitting the center of the detector.

Put the cover on the microscope. It is ready for a computer approach.

If A-B is not stable on the X10 scale, chances are either the Microlever is touching the surface, or it is bad and a new one should be tried. Use the coarse-approach screws to move the Microlevers away from the surface. If the signal remains unstable, try moving the laser spot to the back of the chip. If A-B stabilizes, the Microlever is bad and should be changed.

4.6 Computer Approach

For a computer approach, the control electronics and computer should be set up as described in Chapter 2. The CCU should be connected to the hard disk drive with the 4m HPIB cable and should be plugged into the power strip. The SFM Control Module should be connected to the CCU with a 25-pin connector. The SFM should be set up as described in 4.1, and the base should be connected to the CCU with a 25-pin interface cable.

4.6.1 On the SFM Control Module:

Set the METER switch to show ERROR (the error in the feedback loop) on the BEAM MONITOR panel of the SFM Control Module. Feedback systems try to make the error in the feedback loop zero. In the STM the zero point is the current set value, but in the SFM it is defined by how well A-B is zeroed with a mechanical knob. To fine-tune this zero, there is a nulling knob on the BEAM MONITOR panel.

To zero the error, turn the SETTING knob on the FORCE panel of the SFM control Module to zero and turn the NULL knob until the error is zero.

Set the magnitude of the force with the SETTING potentiometer while looking at the error. The larger the setting, the larger the force while imaging. The MULTIPLIER switch determines the order of magnitude of the force. It can be changed later. A setting of 1 on X10 is a reasonable first guess for almost all samples.

Toggle the deflection direction switch up. If it is up, the feedback will try to make the Microlever bend away from the sample. If it is down, feedback will try to make the Microlever bend toward the sample.

Set the FAST FEEDBACK GAIN on the Z FEEDBACK panel to minimum. GAIN is the gain of the feedback loop.

Set the SLOW FEEDBACK switch on the Z FEEDBACK panel to COMP. The computer will then control the Z piezo.

Set DC LEVEL to TRACK. Otherwise, the signal read by the computer will be DC blocked.

Ignore the other functions on the Control Module for now.

4.6.2 On the Central Control Unit:

Set the X0 AXIS and Y0 AXIS SCAN SIZE to zero on the SCAN CONTROL panel. Otherwise, the sample will be scanning and the tip may crash during approach.

Set the X0 and Y0 DC OFFSETs to 5 on the X10 scale on the SCAN CONTROL panel. Then the tip will be centered laterally in the piezo range.

Set the COMP/MAN switch on the SAMPLE APPROACH panel to COMP. Then the computer will control the stepper motor.

Ignore the other functions on the CCU for now.

4.6.3 On the Computer:

Select SPM Data Acq. from the Shell Program to initialize a scan on the electronics.

Find the trace on the scope using the scope control knobs.

Select Move Sample in the main level of the Data Acquisition program. This menu allows computer control of the stepper motor in the base.

Select Auto Approach. The computer will control the stepper motor and the Z feedback for a crashless approach.

Press <Return> if you have done everything listed in the computer approach checklist.

If you are using the tutorial, watch the Z piezo on the SCANNER MONITOR panel on the CCU and the BEAM MONITOR on the SFM Control Module during the computer approach. The computer has the Z piezo held at mid range and the stepper motor turns the fine approach screw into the base, lowering the tip toward the sample. The ERROR on the BEAM MONITOR meter will start out negative and jump upwards slightly at the last minute. When that happens, the computer will stop the approach, and the piezo will be withdrawn.

If the computer does not stop, even though the error becomes positive, the approach has failed--possibly due to bad set-up or a damaged Microlever. Choose Exit on the menu, and review your set-up and approach.

4.6.4 Activating Feedback

Wait for the computer approach to finish. If it takes too long, check that the COMP/MAN switch is toggled to COMP. You may want to select Exit on the computer to stop the approach and lower the head further manually. Be aware that it is possible to run out of range on the fine-approach screw. If this happens, back up the stepper motor and lower the front of the head further with the coarse approach screws. Ensure that the head is roughly parallel to the base when viewed from the side.

Turn the TIME CONSTANT on the Z FEEDBACK panel of the SFM Control Module up to around 1 to prevent oscillation. This is the time constant of the feedback loop and will be optimized later.

Set the GAIN on the Z FEEDBACK panel to around 0.5 to turn on feedback. This is the gain of the feedback loop, which will be optimized later.

Set the BEAM MONITOR METER switch on the SFM Control Module to ERROR. The Microlever is undeflected since the piezo is withdrawn after the computer approach, so the error should be negative.

Turn the SCANNER MONITOR switch on the CCU to Z to look at the position of the Z piezo.

Switch the SLOW FEEDBACK to AUTO on the Z FEEDBACK panel of the SFM Control Module. The piezo will extend until the feedback deflection is achieved.

Check that the piezo extends about halfway on the SCANNER MONITOR and stops. If the piezo keeps extending and does not stop, the approach failed, usually due to the reflection of excess scattered light from the sample into the detector. Re-initiate the Auto Approach.

Check that the error becomes zero on the meter of the BEAM MONITOR panel on the SFM Control Module. The error will become zero as the force on the Microlever becomes equal to the set force.

If you are using the tutorial, change the FORCE MULTIPLIER from 10 to 100 on the SFM Control Module and watch the position of the Z piezo change on the SCANNER MONITOR on the CCU. Change the FORCE SETTING and watch the Z piezo position change.

If the Z piezo is not in the center of its range, use the stepper motor that drives the fine approach screw in the base to lower the head toward the sample or raise it away from the sample. When the piezo is not near the center of its range, it may run out of range during scanning if the sample is tilted or very rough. If the Z piezo is extended too far (the bar graph is lit up on the right hand side) move the tip toward the sample (FWD). Likewise, if the Z piezo is fully withdrawn (the bar graph is lit up on the left side) move the tip away from the sample (BWD)

Note: To protect the tip, it is a good idea to withdraw the sample with the SLOW FEEDBACK switch on the SFM Control Module before using the stepper motor. Move about ten steps at a time.

Appendix 4A Preparing the Microlever Chip

Microlevers are on chips, which are contained in a wafer. The following procedures show you how to separate strips of Microlevers from wafers and break off chips from strips of Microlevers. Figure 4A-1 shows the tools in the Chip-Handling Tool Kit that will be referred to in the following procedures.

Caution: The Microlevers are easily damaged. To protect them, carefully follow the procedures outlined below.

4A.1 Separating a Strip of Microlevers

If you are using the tutorial, observe the wafer while it is still in its container. Use a high-powered optical microscope, if you have one, to inspect the wafer first. The wafer has been sawn into strips, as shown in Fig. 4A-2.

The strips have been sawn two-thirds of the way from the back side into chips and spacers. The chips have four Microlevers on one end, two on the other. The wider spacers do not have Microlevers. The SFM tips stick up from the Microlevers. The chips are 4mm by 2mm, and there are 293 chips per wafer.

The wafer is made of glass and is surrounded by a silicon ring which is covered by a foam spacer. The glass is covered with silicon nitride, from which the Microlevers are microfabricated. The bottom surface (including the back of the Microlevers) may be coated with gold or chrome.

Prepare a work surface for the wafer. The surface should be flat and clean, in an area that is not too cramped. A large glass plate or machined metal surface will work well. The aim is to minimize the risk of damaging the Microlevers.

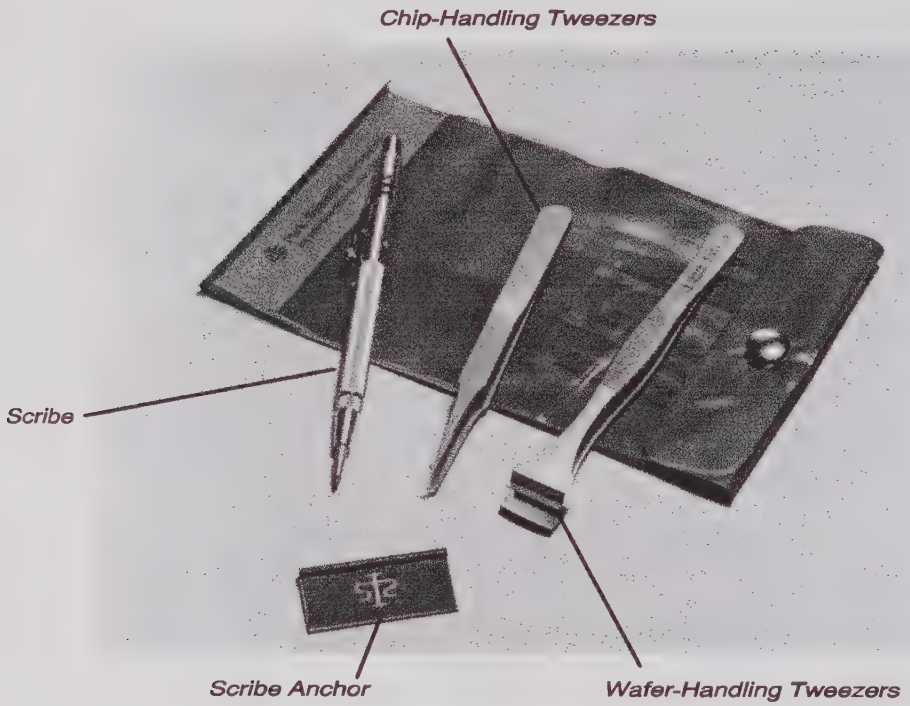


Fig. 4A-1 Chip-Handling Tool Kit

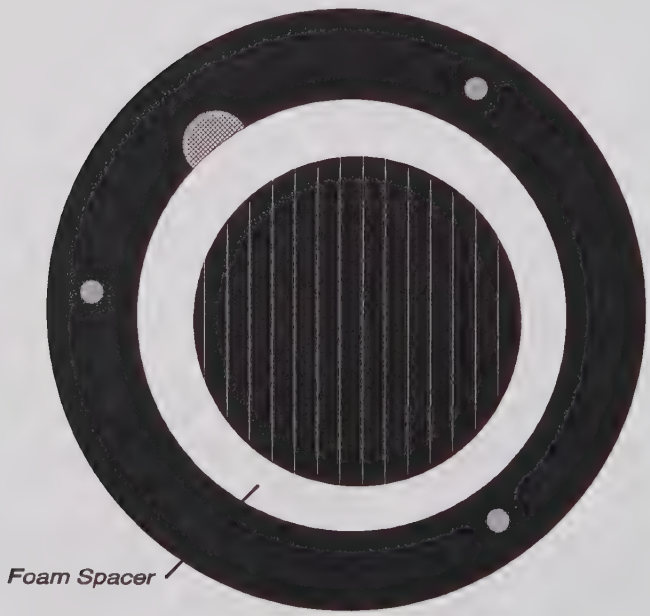


Fig. 4A-2 Microlever Wafer

Remove the three screws while holding the plexiglass plate in place, and lift the plexiglass plate together with the foam spacer. Be sure that the wafer is not lifted off the bottom plate.

Pick up the wafer by its silicon ring with the wafer-handling tweezers provided in the Chip-Handling Tool Kit, and Put it on the work surface with the outer silicon ring facing up. The Microlever tips are on the side with the silicon ring.

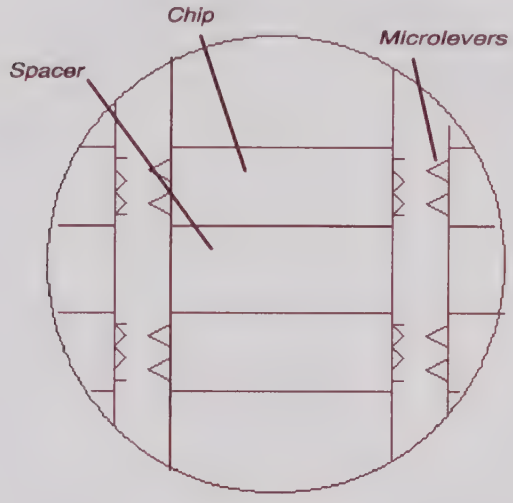


Fig. 4A-3 Microlevers

Full Wafer: When starting with a full wafer, you will first have to break off part of the silicon ring to expose the first strip of Microlevers.

Using the edge of the glass microscope slide as a straight edge, scribe a line on the silicon ring on both sides of the wafer perpendicular to the wafer flat, with the tungsten-carbide scribe in the Chip-Handling Tool Kit. Make the line so as to just expose the first strip of Microlevers. (Refer to Fig. 4A-4.)

Lift up one side of the wafer and set it over the edge of the glass slide so that the scribe line is over the edge of the glass slide.

Use the scribe anchor in the Chip-Handling Tool Kit to hold down the wafer at the silicon ring and press with the flat end of the scribe on that part of the ring that is hanging over the edge.

Repeat this on the other side of the wafer to break off the edge of the silicon ring and expose the edge of the first strip of chips. Be careful not to touch the Microlevers that are now exposed. Remember, the Microlevers are pointing out from the newly exposed edge. If anything touches the edge, it will ruin many Microlevers.

Partial Wafer: Once part of the silicon ring has been broken off (or if only working from a partial wafer), you can break off a strip of Microlevers.

The wafer should be on the flat, clean work surface.

Using a glass microscope slide as a rule, scribe a line on the silicon ring on both sides of the wafer, between Microlever strips with the tungsten-carbide scribe in the Chip-Handling Tool Kit. If you hear a squeaking sound, you have scribed enough. (Refer to Fig. 4A-7.)

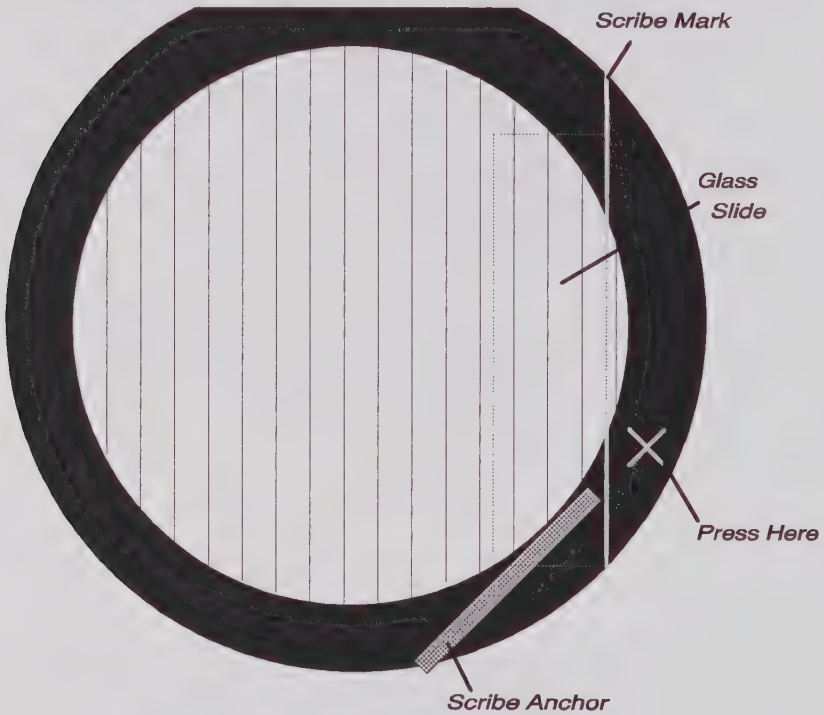


Fig. 4A-4 Breaking the Silicon Ring

Lift up one side of the wafer and set it over a microscope slide so that the scribe mark is over the edge of the slide. Hold the wafer down with the scribe anchor, and, with the flat end of the scribe, press on the silicon ring to free one end of the strip.

Break the Si ring on the other side of the wafer in the same way so that a strip will be detached. Realize that the Microlevers are on both of the edges of the strips, so take great care to avoid letting the edges bump into the wafer or anything else.

Caution: Be careful with the strip of Microlevers; there are Microlevers on both sides. Break off strips of Microlevers only as they are needed. The silicon ring provides a good support structure, so keep the wafer safe by storing it in the container in which it came.

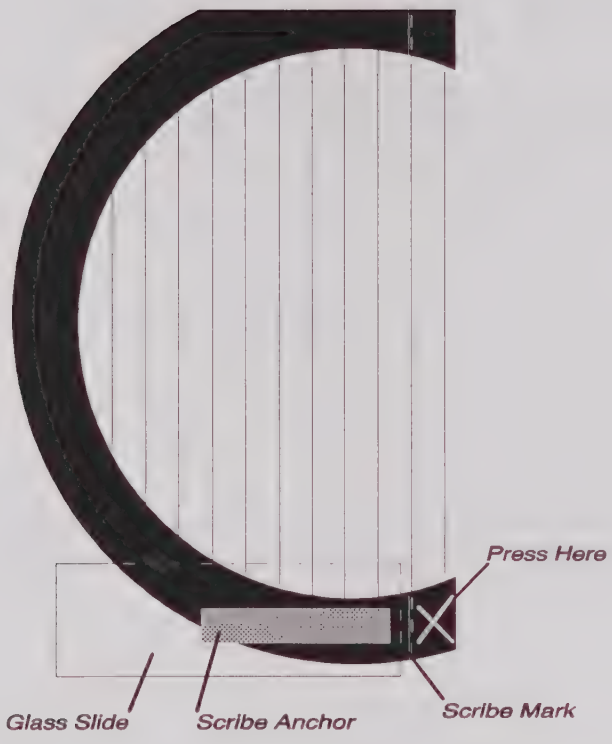


Fig. 4A-5 Breaking One Edge of the Silicon Ring

4A.2 Breaking Off a Microlever Chip

Put the strip on top of the glass microscope slide, holding it at the Si ring with the wafer-handling tweezers from the Chip-Handling Tool Kit. Fig. 4A-6 shows a Microlever strip; you should be able to see Microlevers on both sides.

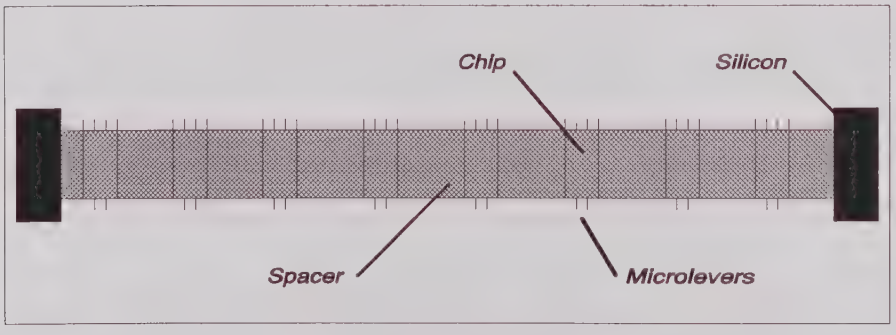


Fig. 4A-6 Strip of Microlevers

The back of the strip has been sawed two-thirds of the way through, between the chips and spacers. However, the strips are made of glass and require a lot of force to break if not scribed first.

Hold the strip down with the scribe anchor in the Chip-Handling Tool Kit to keep it from rotating, making sure the rubber does not touch the Microlevers. (Refer to Fig. 4A-7.)

Note: If the scribe anchor touches the Microlevers, they will be ruined.

Make scribe marks on the top side of the strip, over the saw cut, just enough to hear squeaking. Be careful to scribe only near the center of the chip. If the scribe falls over the sides of the chip, it may break the Microlevers.

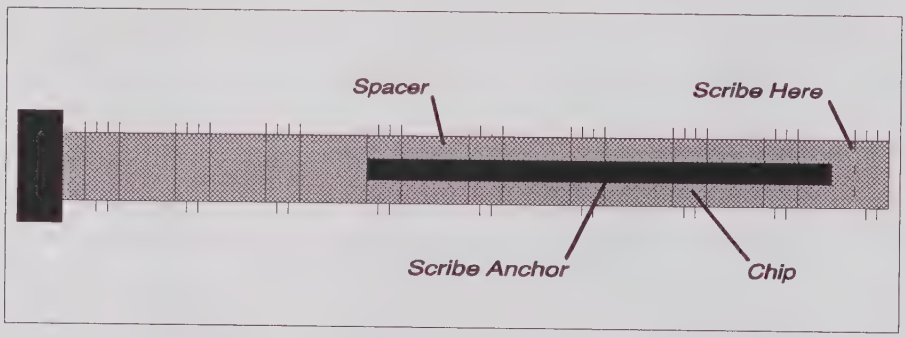


Fig. 4A-7 Scribing a Microlever Strip

Slide the strip so that the chip or spacer hangs over the edge of the microscope slide.

Use the back end of the scribe, held vertically, to press on the chip or spacer. (Refer to Fig. 4A-8.) If it is a chip with Microlevers, be careful not to press too near the Microlever to be used. The chip should break along the scribe line.

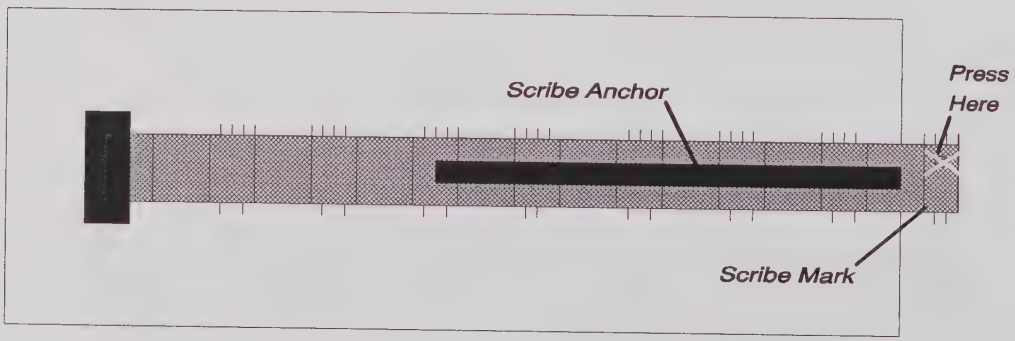


Fig. 4A-8 Breaking Off a Chip

If it is a chip with Microlevers, use the chip-handling tweezers to pick it up by the longer sides.

Store the strip of Microlevers under a cover which does not touch them, to keep out dust and protect them. Make sure they will not be disturbed. Also make sure that the strips or chips never turn upside down, as this will destroy the Microlevers.

To get good images, protect the Microlevers carefully. Nothing should touch them, including dust.

4A.3 The Microlevers

Microlevers, micro-fabricated from low-stress silicon nitride, are highly resilient with force constants ranging from 0.4 to 0.03 N/m. Integrated pyramidal tips have nominal radii of less than 400 Å. The structure is illustrated in Fig. 4A-9.

Each Microlever chip has six Microlevers, illustrated in Fig. 4A-10. (The Microlever and chip dimensions are not to the same scale.)

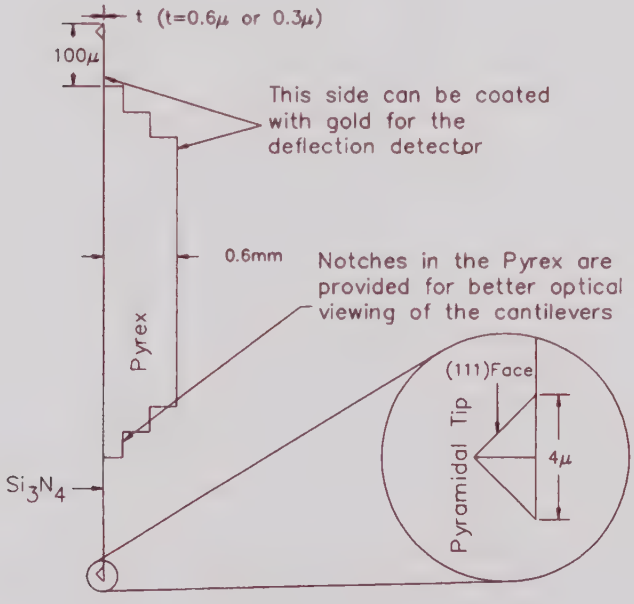


Fig. 4A-9 Side View of Microlever Chip

For 0.6-μ thick Microlevers, the theoretical force constants and resonant frequencies are:

Shape	L(μ)	w(μ)	Force Const. (N/m)	Res. Freq. (KHz)
"V"	100	13	0.21	66
"V"	100	22	0.37	66
"V"	200	18	0.032	17
"V"	200	36	0.064	17
Rect.	100	10	0.08	66
Rect.	100	20	0.17	66

The 100-μ long, 22-μ wide V-shaped Microlever is suitable for most purposes. The rectangular Microlevers can twist and are useful for stiction studies.

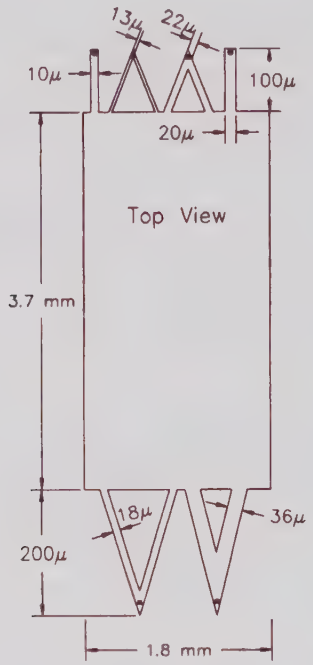


Fig. 4A-10 Microlever Chip Top View

Appendix 4B Preparing Samples for SFM

The maximum sample size that can be accommodated is about 1" by 1" by .5" thick.

Standard SEM stubs are used to hold samples, which may be fastened to the stub with double-sided sticky tape, or with epoxy. If using tape, be sure it is flat, since bubbles and folds will prevent proper adhesion. Also make sure the sample is securely attached.

Another possibility is to use clips to hold the sample down. Some special sample holders are available from PSI, as shown in Fig. 4B-1.

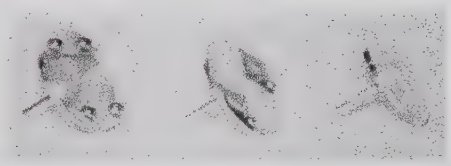


Fig. 4B-1 Special Sample Holders

Some samples build up electrostatic charge; for those, a conducting pathway should be made to carry away excess charge. Oxidized semiconductors are particularly susceptible to electrostatic charging. Using a sample holder with conducting clips alleviates the charging in most cases.

Take care in making the sample's surface as level as possible. Leveling the sample at the start will minimize the need for electronic tilt correction.

If the sample is not well secured, it will slide around, preventing good imaging.

The surface can be cleaned with compressed air if desired.

Appendix 4C Using the 1000X Optical Microscope

Warning: Use of controls or adjustments, or performance of procedures other than those specified herein may result in hazardous laser light exposure.

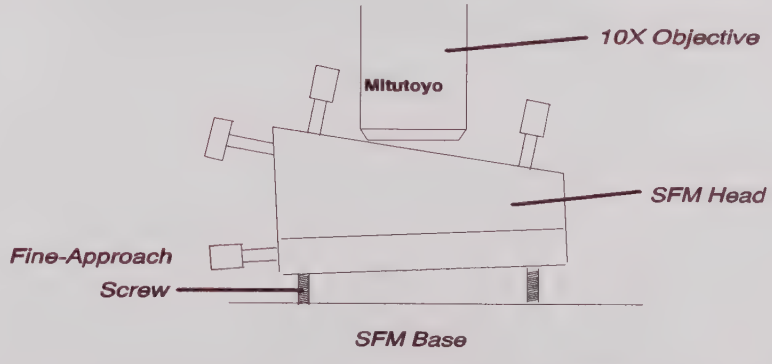
The optical microscope provides on-axis viewing of the tip-sample region and facilitates quick placement of the Microlever over a desired imaging area. The optical microscope should be set up as described in Appendix 2A. The SFM should be set up and prepared as described in sections 4.2-4.4.

Place the SFM base and head on the translation stage of the optical microscope. Orient the base so that the coarse-approach screws lie parallel to the front face of the translation stage. The optical microscope head should be rotated out of the way.

Rotate the optical microscope head back over the SFM head. Use the focus knob to make sure the objectives are raised high enough to ensure that they will not hit the SFM head.

Rotate the turret to use the 10X objective. With SFM the 10X objective is the only one that provides sufficient working distance.

Caution: There is very little clearance between the objective and the SFM head. To avoid hitting the SFM head with the objective, tilt the SFM head back slightly, toward the fine-approach screw.



Turn on the light source and rotate the 1000X microscope head to ensure that the spot falls squarely on the sample. Use the large translation stage adjustment screws if necessary. To save time, you may want to re-position the SFM head on the large translation stage.

Focus the optical microscope until the sample is in view, making sure the objective does not hit the SFM head. Use the large translation stage to pinpoint the desired feature.

Use the SFM head translation stage to place the chosen Microlever directly over the desired spot. To minimize approach time, you may find it useful to use the 120X (off-axis) optical microscope to bring the Microlever as close to the sample as possible.

The SFM can be operated with the optical microscope light source on and the SFM cover off, but this may introduce some 60-Hz noise. For rough surfaces (1000 Å) this should not be noticeable, but for smooth surfaces the optical microscope should be rotated out of the way and the cover should be put on the SFM.

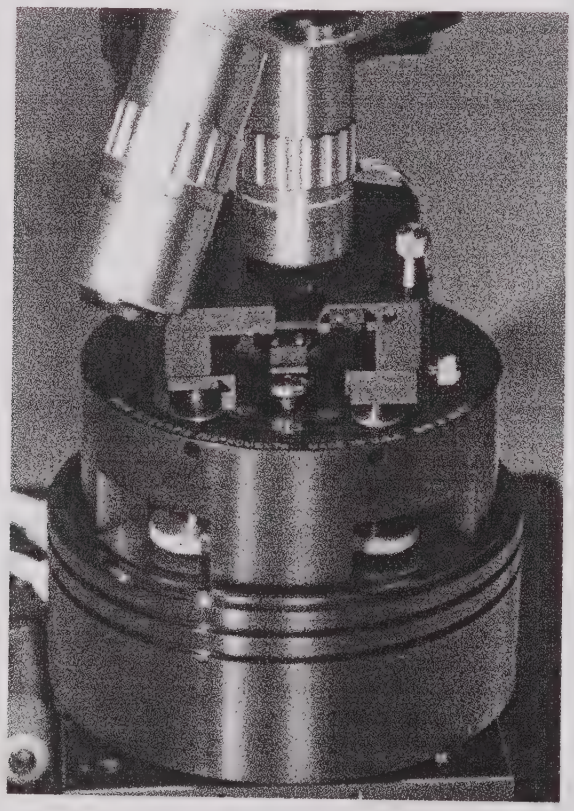


Fig. 4C-1 1000X Optical Microscope with SFM

5 Scanning and Taking Images

Changing Parameters on the Computer
Setting the Electronics for Scanning
Correcting for Slope
Adjusting Scan Parameters
Taking Images
Changing the Scan Region
Buffer and Data Storage
Imaging Strategies
Shut Down
Calibration

The computer and electronics should be set up as described in Chapter 2. The microscope should be set up as described in Chapter 3 or 4 (using the calibration grating if you are going to use the tutorial), and you should make a computer approach as described in one of these chapters. SLOW FEEDBACK should be set to AUTO on the Control Module.

If this is your first time, you should use the tutorial sections of this chapter. They assume that you are imaging the calibration grating.

5.1 Changing Parameters on the Computer

Some parameters are set on the computer. They can be changed later, but you should think about them before scanning. The scan rate must be set before scanning to avoid damaging the tip. The SPM mode must be set before taking images, as it determines how data are acquired. The time and date should be set when you are just starting. The piezo sensitivities are found through calibration and are unique to each scanner; the first time through they should be set to a value set by PSI. The data storage device should be set before you save data. The linearity factor and tilt power should be set before taking images.

5.1.1 Setting the Scan Rate

It is important to set the scan rate before scanning to avoid damaging the tip, although the scan rate can be changed later. Realize that the FAST FEEDBACK parameters, described in Section 5.4.2, are scan-rate dependent.

Set the X0 scan rate in the Set Up menu. Feedback tracks better at slower scan rates. Fast scan rates are useful for saving time and for constant-height images when you don't want feedback to track well. If you scan too quickly, feedback may not be able to keep up with all features and the tip may crash. This will reduce the lifetime of an SFM tip and damage an STM tip. Typically, 2-8 Hz is a good value for constant-current/force images for almost all scan sizes. 25-65 Hz is good for constant-height images and should be used for small scans (< 1000 Å) and flat surfaces.

If you are using the tutorial, set the X0 scan rate to 4 Hz for STM or 8 Hz for SFM.

5.1.2 Setting the SPM Mode and Bias Polarity

The SPM mode and bias polarity (if you are using STM) must be set before taking images as it determines how data are acquired.

Set the SPM mode in the Set Up Menu. Mode 1 is appropriate for initial scans because it is fast and allows for spectroscopic studies. Mode 2 generates higher resolution images but is slower. For a discussion of the other imaging modes, refer to Section 10.1.1.

To change the tunneling bias for STM you must reset the SPM mode. The bias polarity is that of the tip relative to the sample, which is grounded.

If you are using the tutorial, set the SPM mode to 2.

5.1.3 Setting the Time and Date

If this is your first time, set the time and date in the Set Up menu.

5.1.4 Setting the Piezo Sensitivities

The piezo sensitivities are unique for each scanner. They should be set initially and changed when you change scanners or calibrate them.

Check the piezo sensitivities in the Extended Configuration option of the Set Up menu. You may want to change them. PSI calibrates every tube sent with the instruments. If this is your first time using a scanner, use the values indicated on the tube. They should be close to the approximate values given in the table below.

	Z	X,Y
2.5 μ	40 Å/V	60
10 μ	80	240
35 μ	160	960
75 μ	230	1900

Realize that calibrations change with time and with conditions of use, such as scan speed. The calibration procedure is given in Appendix 5A. Calibration is essential for accurate measurements due to its dependence on scan conditions and should be done regularly. Ideally you should calibrate the scanner under the same conditions under which the data is taken.

5.1.5 Setting the Data Storage Device

The data storage device should be set before you save data.

Check the Data Storage Device in the Extended Configuration option of the Set Up Menu. For most users, :,700,1 is the floppy disk drive and :,700,0,1 and :,700,0,2 are the two available hard disk drives .

5.1.6 Setting the Linearity Factor

The linearity factor should be set before taking images, as it affects the data that are collected.

Set the Linear Factor in the Display Options menu. When the linearity factor is 1, non-linearity in X0 is corrected as data are collected. If it is 0, they are not corrected. They will be corrected only if you have calibrated the non-linearity of your scanner using the Image Processing program. The calibration procedure is described in Appendix 5A.

If you are using the tutorial, or if you are taking an image to calibrate the scanner, set the linearity factor to 0.

5.1.7 Setting the Automatic Tilt Correction

The tilt correction is a coarse adjustment to the background that is made as the data are collected.

Set the Tilt Power in the Display Options menu. If you set it to 1, the first line of data will be fitted to a line which will be subtracted from each subsequent trace. If you set it to 3, the first line of data will be fitted to a third order polynomial which is subtracted from each subsequent line. If it is zero, no correction is made. For simple sample tilt, a first-order correction should be used. For a very flat sample (< 100 Å roughness) at large scan sizes, a third order correction should be used. It is almost always a good idea to to have a tilt power of 1 to get rid of any DC offset. Sometimes using the third order correction will convolve the sample topography and tube curvature. Therefore, it might be better to tilt correct with a power of 1 and perform the higher-order correction during image processing, where the entire image can be corrected at once.

If you are using the tutorial, set the tilt power to 1.

5.2 Setting the Electronics for Scanning

5.2.1 On the Control Module

You should set the switches on the Control Module to initial values. You can change them all later. Switches not described here should have been set as described in Chapter 3 or Chapter 4. The two switches described here have no effect on the junction/deflection condition.

Set the SOURCE to Z (for STM or SFM) or log(I) (for STM) or A-B (for SFM). This switch determines which signal is used for data acquisition. Z is the most common source for data acquisition.

If you are using the tutorial, set the SOURCE to Z.

Set the IMAGE ACQUISITION GAIN to an initial value. The GAIN switch determines by how much the image signal will be amplified before going through the A to D converter. Set it to 1 for now.

If you are using the tutorial, set the IMAGE ACQUISITION GAIN to 1. The FAST FEEDBACK GAIN should be 1 and TIME CONSTANT 5 for STM and 2 for SFM. SLOW FEEDBACK should be set to AUTO. DC LEVEL should be TRACK.

If you are using the tutorial with STM, check that the TUNNELING VOLTAGE is 0.2 V and the CURRENT is 1 nA. If you have to toggle a switch, withdraw the sample first by switching SLOW FEEDBACK to WDRW. When you are done switch it back to AUTO.

5.2.2 On the CCU

The switches on the CCU should be set to initial positions.

Set the SCOPE MONITOR switch to IMAGE DATA and turn up the scope gain. This refers to SOURCE on the IMAGE ACQUISITION panel on the Control Module. When SOURCE is set on Z, the scope shows the signal applied to the Z piezo, less some DC filtering and slope correction. When SOURCE is set on log(I) in the case of STM or A-B in the case of SFM, the scope displays the error in the feedback loop.

Set the SCAN SIZE MULTIPLIER on the SCAN CONTROL panel. This switch determines the range of scan sizes available, and can be changed later. When set to 100, scan sizes from zero to the full range of the scanner (2.5 μ or 10 μ) are possible. When set to 10 or 1, scan sizes from zero to one-tenth or one-hundredth, respectively, of the full range are possible.

If you are using the tutorial, set the SCAN SIZE MULTIPLIER to 100.

5.3 Correcting for Slope

By correcting for slope, you use the A/D converter and feedback circuit more efficiently. To minimize tilt, it is helpful to scan in the center of the sample if possible.

5.3.1 Correcting for Slope in the Y0 Direction

With large, fast scans, or when using Continuous Image, it may be necessary to correct for slope in the Y0 direction.

If you are using the tutorial, you can just set the Y0 SLOPE knob to 0.

With the SCAN SIZEs at 0, turn the ROTATION knob to 90° so that the scan will be in the Y direction. The scope will display Z vs. Y.

Turn the X0 AXIS SCAN SIZE potentiometer up until you see a fair representation of the surface. The X0 axis is the axis that is scanned constantly and displayed on the CCU scope. Because the rotation is set to 90°, X0=Y in this case. Whenever there is a trace on the scope and the X0 AXIS SCAN SIZE is not zero, the sample is being scanned.

Turn the X0 SLOPE knob and make the trace on the scope as level as possible. In this way you can determine what slope correction that is necessary in the Y direction.

Set the Y0 SLOPE knob to the position of the X0 SLOPE knob. The Y0 axis is the slow scan direction; it is only scanned when you take an image.

Turn the X0 SCAN SIZE to 0 and rotate back to 0°. The scope will then display Z vs. X. In this case X0=X.

5.3.2 Correcting for Slope in the X0 Direction

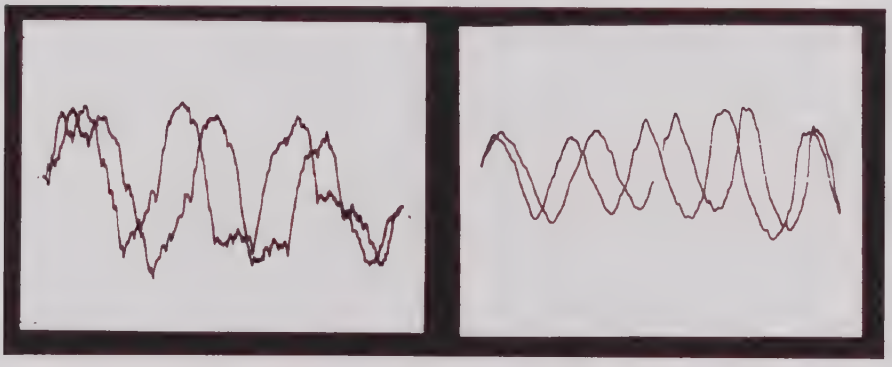
You should always correct for slope in the X0 direction, although fine adjustments to the slope can be made in the image processing section of the software after the data has been collected.

Turn the X0 AXIS SCAN SIZE potentiometer up to the desired scan size to start a scan.

If you are using the tutorial, turn the X0 AXIS SCAN SIZE potentiometer to 5. Then turn the X0 SLOPE knob all the way in both directions and watch the trace on the scope rotate.

Turn the X0 SLOPE knob to make the trace on the scope level. If the sample is very tilted relative to the scan plane, it may not be possible to get rid of all of the slope.

If you are using the tutorial, the trace on the scope should look like Fig. 5-1.



Trace Using STM *Trace Using SFM*

Fig. 5-1 Scope Trace Using Grating

5.4 Adjusting Scan Parameters on the Control Module

Learn how to optimize the scan parameters. It is important that you optimize them if you want to get good images.

5.4.1 Adjusting IMAGE ACQUISITION GAIN

The IMAGE ACQUISITION GAIN is outside of the feedback loop so turning it will not damage the tip or sample.

If you are using the tutorial, switch the IMAGE ACQUISITION GAIN from 1 to 10 and watch the trace on the scope become 10 times larger. Switch the GAIN from 10 to 100 and reduce the gain on the scope, and watch the trace become flat-topped as the amplifier is saturated.

Turn the IMAGE ACQUISITION GAIN switch as high as possible before the trace on the scope shows saturation (becomes flat-topped). In this way the A/D converter will be used most efficiently.

5.4.2 Adjusting FAST FEEDBACK GAIN and TIME CONSTANT

These parameters are within the feedback loop, but changing them carries little risk of damaging the sample or tip.

If you are using the tutorial, turn the FAST FEEDBACK GAIN up to 10 and the TIME CONSTANT to 0.5 to make the system oscillate. Fig. 5-2 shows a scope trace of the calibration grating with oscillation. Turn the GAIN down until oscillation stops; the scan on the scope should show many small features, indicating optimal feedback. Fig. 5-3 shows a scope trace with optimized feedback parameters. Turn the GAIN down to 1 and TIME CONSTANT up to 10 and notice that features wash out (Fig. 5-4).

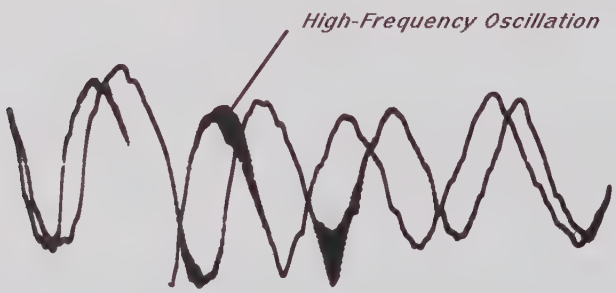


Fig. 5-2 Calibration Grating Trace Showing Oscillation

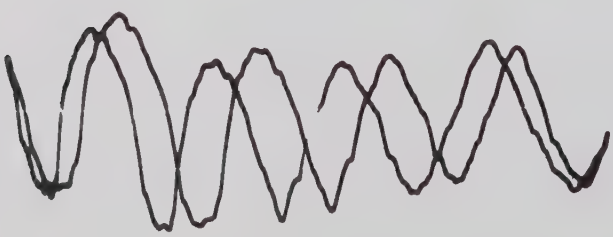


Fig. 5-3 Calibration Grating Trace with Feedback Parameters Optimized

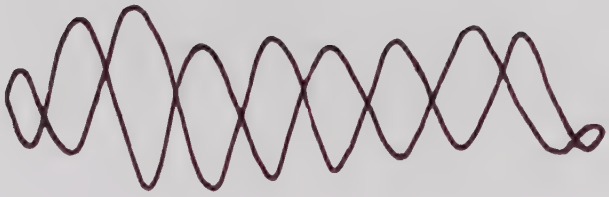


Fig. 5-4 Calibration Grating Trace at Low Gain and High Time Constant

Adjust the FAST FEEDBACK GAIN and TIME CONSTANT so that the trace on the scope is as detailed as possible. These refer to the gain and time constant of the feedback loop. The higher the gain, the more accurately the microscope can track features. The smaller the time constant, the faster the microscope can respond to features as it scans. But if the gain is too high and the time constant too low, the feedback loop will oscillate. Adjust the gain as high as possible and the time constant as low as possible, keeping the system from oscillating. This is the point where the feedback parameters are optimized.

If the gain is too low or time constant too high, small features will be washed out; if the gain is too high or time constant too low, oscillation will occur. For each value of the time constant there will a different value of the gain that brings the system to the verge of oscillating. Also, the optimum gain and time constant will depend on the scan speed, scan size, sample surface topography, and other factors. For that reason, you should optimize these parameters each time.

5.4.3 Adjusting Junction/Force Parameters

These parameters are within the feedback loop, and, if improperly set or changed abruptly, could damage the tip.

If you are using STM, adjust the bias-voltage and tunneling current as necessary to improve the trace on the scope.

Note: If you flip the VOLTAGE or CURRENT switch, the junction condition will change abruptly and feedback cannot keep up. You should switch SLOW FEEDBACK to WDRW before toggling these switches.

If you are using SFM, you may want to adjust the FORCE SETTING and MULTIPLIER to improve the trace on the scope. Usually this will have little effect unless the sample is very soft.

Note: If you switch the MULTIPLIER switch, the junction/force condition will change abruptly and feedback cannot keep up. You should switch SLOW FEEDBACK to WDRW before switching the MULTIPLIER.

5.5 Generating an Image

So far the sample has been scanning in one direction only (X0). Scanning in the Y0 direction to generate an image is initiated through the software.

5.5.1 Taking an Image

Go to the Take Data menu in the Data Acquisition program.

Set the Y0 SCAN SIZE the same as the X0 SCAN SIZE while looking at the screen. The image will be displayed square in any case, so it is best to make the scan sizes equal.

If you are using the tutorial, set the X0 and Y0 AXIS SCAN SIZEs to 5. Set the ROTATION to zero so the X0 axis corresponds to the X piezo. Leave the DC OFFSETs at 5 so that the scan will be centered in the scanner range.

Select Take Image. A gray-scale image will appear on the left side of the screen, and an amplitude trace will appear on the right.

5.5.2 Changing the Display Amplitude

You will probably want to change the Display Amplitude to use the gray scale more efficiently.

Select the Display Amplitude option in the Display Options menu.

If you are using the tutorial, set the gray-scale amplitude to 10 Å and offset to zero. The image will be saturated (black and white only) because the display amplitude is too small. Change the display amplitude to 40000 Å and leave the offset at 0, and notice that the contrast of the image is decreased. Set the amplitude to 2000 and offset to 0; the gray scale should be nearly optimized. Change the offset to 1000 and notice that the image becomes lighter.

Enter a new amplitude and offset as necessary to optimize use of the gray scale. The amplitude is the number of angstroms corresponding to full scale of the gray scale, and the offset is the number added to each data point. Decrease the amplitude to increase the contrast.

5.6 Changing the Scan Region

5.6.1 Changing the Scan Size and Position

Use the knobs on the SCAN CONTROL panel to change the scan size and position. You can look at features directly on the scope, in real time.

Note: Reduce the SCAN SIZE to zero before changing the MULTIPLIER or ROTATION.

If you are using the tutorial, slowly turn the X0 SCAN SIZE from 5 to 9 and watch the number of gratings in the trace increase. Reduce the X0 SCAN SIZE to 5 again, and slowly increase the 10 X DC OFFSET to 8 and watch the gratings move to the left on the scope. Notice the X clipping lights that indicate that the scan position exceeds the piezo range.

5.6.2 Using the Display Window

The Display Window option is a convenient way to see what region you have scanned and to close in on a particular feature.

To use the Display Window, select the Display Window option from the Take Data menu.

Use the knobs on the SCAN CONTROL panel to change the scan size and position. The outer square shows the maximum scanner range, and the inner rectangle shows the current scan position.

If you are using the tutorial, select the Display Window option. Set the X10 DC OFFSETs to 5 and X0 and Y0 AXIS SCAN SIZEs to 9, then exit the window to take an image. Select the Display Window option again, and reduce the SCAN SIZEs to 5. Change the X10 Y DC OFFSET to 8. Notice that the scan range exceeds the maximum scanner range, but the CLIPPING lights on the CCU do not go on. The sample is being scanned in the X0 direction only, at the bottom of the Y0 range and thus within the scanner range. Reduce the X0 and Y0 SCAN SIZEs to zero, switch the MULTIPLIER to 10, then turn the SCAN SIZEs up to 10. Exit the window to take an image. Reduce the SCAN SIZEs to zero again, set the ROTATION to +30°, then turn the SCAN SIZEs up to 10. Exit the window to take an image, and notice that the gratings have been rotated counterclockwise 30°. Reduce the SCAN SIZEs to 0 again, and set the ROTATION to 0 and MULTIPLIER to 100. Set the SCAN SIZEs up to 8 each and DC OFFSETs at 5 each, and take another image.

You can select Close-Up from the Window menu to close in on a feature of interest. This option lets you see where the current scan position (determined by the knobs on the SCAN CONTROL panel of the CCU) is relative to the previous scan.

If you are using the tutorial, select the Close-Up option. The last image you took will be displayed in the center of the screen, and the inner rectangle shows the current scan position. A red border (indicating the maximum piezo range) may be present. Reduce the SCAN SIZEs and use the DC OFFSETs to close in on a single grating peak, then take an image.

To take an image, exit the Window option to the Take Data menu and select Take Image.

5.7 Buffer and Data Storage

When you take images they are automatically saved in the buffer but not on disk.

5.7.1 Saving Images

If you have taken an image, use the options in the Save Menu to change the data name, sample name, and comment if desired. For example, select Sample Name, type `calibration grating` and press <Return>; note that the heading has changed.

If you are using the tutorial, give the last image you took a comment and sample name.

Select Save to save the image to the hard disk or floppy. Make sure you have selected the data storage device in the extended configuration as described in Section 5.1.5.

If you are using the tutorial, save this last image.

5.7.2 The Buffer

When you take images they are automatically stored in the buffer.

To see images in the buffer, enter the Buffer Menu. This menu lets you look at the images in the buffer and save them. You can use the Goto Nth, Previous Buffer, and Next Buffer options to look at different buffered images.

If you are using the tutorial, use the Buffer Menu to look at the images you took. The image that you saved to disk is no longer in the buffer.

To save a buffered image, select Save from the Buffer Menu or go to the Data Storage menu for more options. The Save Menu option in the Data Storage menu lets you change the data name, sample name, and comment.

If you are using the tutorial, save all of the images you took.

5.8 Imaging Strategies

5.8.1 The Time Constant for DC Blocking

For most images DC blocking is useful for removing tilt. However, in some images, particularly those with large features or steps, DC blocking may introduce filtering artifacts.

Set the TRACK/HOLD switch on the Control Module to optimize DC blocking. This switch is outside of the feedback loop so it does not affect the junction/force condition. For most purposes, TRACK is appropriate.

If you are using the tutorial, set this switch to HOLD and take an image. If there is any slope in the Y0 direction, the image will show this slope. Notice that the trace on the scope is no longer centered because of a DC offset. Set this switch on TRACK again and watch the trace become centered again.

5.8.2 Feedback and Signal Images

For most scans constant-current or constant-deflection mode is appropriate. However, for small scans, particularly atomic studies, constant-height may give better images.

Set the SOURCE switch on the Control Module to select the signal that will be displayed on the scope and computer. This switch is outside the feedback loop, so it does not affect the junction/force condition.

If you change the source, you will have to reoptimize the FAST FEEDBACK GAIN and TIME CONSTANT. If the source is Z, the signal driving the Z piezo, GAIN should be high and the TIME CONSTANT low so the system operates in constant-current or constant-deflection mode. If the source is log(I) or A-B, GAIN should be low and the TIME CONSTANT high so the system operates in constant-height mode.

If you are using the tutorial, reduce the SCAN SIZEs to zero, set the MULTIPLIER at 10, and then turn up the SCAN SIZEs to 5. Toggle the SOURCE switch to log(I) if you are using STM, or A-B if you are using SFM, so that the scope shows the error in the feedback loop. Reduce the FAST FEEDBACK GAIN to 0.2 and increase the TIME CONSTANT to 10 and watch the error increase as feedback tracks features less well. You should see some sample features in the error signal. (To take an error image, the scan size should be very small--no larger than about 100 Å--and the scan rate should be fast--from 25 to 60 Hz.

5.8.3 Tilt Correction

If you are unable to compensate electrically for all the tilt in the sample, you can use a real-time tilt correction to do so. Moreover, curvature due to the geometry of a tube scanner can be removed with a real-time curvature correction. Fine tuning of tilt and curvature correction can be accomplished by using the Tilt Correction menu of the Image Processing program in addition to the real-time corrections.

To activate or de-activate the real-time tilt correction, select Tilt Power in the Display Options menu.

Set the tilt power to 0 to turn it off, to 1 for a first-order correction, or to 3 for a third-order correction. If you set it to 1, the first line of data is fitted to a line and this line is subtracted from each subsequent line of data. If you set it to 3, the first line of data is fitted to a third order polynomial which is subtracted from each subsequent line of data.

If you are using the tutorial, set the tilt power to 0 and turn the X0 SLOPE knob so that the trace on the scope is tilted. Take an image and notice that this tilt appears in the image. Set the tilt power to 1 and take an image; the tilt will not appear in the image.

5.8.4 X0 Linearity Correction

You can correct for piezo nonlinearity in the X0 direction as you take data. You can also correct for nonlinearity in both X0 and Y0 directions in the Image Processing program.

To turn on or off the real-time X0 linearity correction, select the Linear Factor option in the Display Options menu.

Set the linear factor to 0 to turn off the correction or to 1 to turn it on. If you set the Linear Factor to 1, then as data are collected they will be corrected for nonlinearity in the X0 direction. If you set it to 0, they will not be corrected.

5.9 Shut Down

If you want to shut down, switch SLOW FEEDBACK to WDRW and reduce the SCAN SIZE to 0. Then the sample is pulled away from the tip.

Back the tip away from the sample about 400 steps using the SAMPLE APPROACH panel on the CCU. Toggle the COMP/MAN switch to MAN, and the FWD/BWD switch to BWD.

Turn off the electronics.

If all files have been saved, just turn down the brightness of the monitor. You don't have to turn off the CPU, hard disk drive, or monitor.

Caution: Remember that if you unplug the SFM head from the base you should first turn off the power on the SFM Control Module.

If the tip and sample are still in good condition, you can reuse them when you start.

Appendix 5A Linearity Correction and Calibration

The piezo scanner is non-linear and changes with time. You should regularly calibrate the scan size and linearity. If you are taking a very important image, you should calibrate the scanner immediately before or afterwards.

5A.1 Generate a Calibration Image

To calibrate the scanner you need to take an image of the calibration grating supplied with your system, or some other known calibration standard.

In the Display Options menu of the Data Acquisition program, set the Linear Factor to 0. Then the existing linearity correction will not be used.

Take and save a full-scale (9.5 x 100) image of the calibration grating with low FAST FEEDBACK GAIN (0.2) and high TIME CONSTANT (10), using Mode 2. The sample should be oriented to be as parallel as possible to the X axis (the imaginary line connecting the two coarse-approach screws. Rotate the scan as necessary so that the axes of the grid correspond to the X0 and Y0 axes; you may have to rotate the sample in the sample holder. If you have an SFM, use it to take this image.

Exit the Data Acquisition program and run the Image Processing program.

Select the Load option and load the image.

5A.2 Determine Linearity Coefficients

Calibrating the linearity involves using the Image Processing program to calculate four linearity coefficients.

In the Set Up menu, select the Linearity Factors option and ask to measure the linearity factors.

Use the mouse to position the horizontal line through the minima, and press the mouse button.

If the red lines correspond to the minima of the cross section, accept the calibration. It is possible that small features on the grating will we interpreted as minima; this is why the image was generated with low GAIN and high TIME CONSTANT.

When you say that you are sure to use this fitting, it will be saved on the data storage device.

If you want to correct X0 nonlinearity as data are taken, set the Linear Factor to 1 in the Display Options menu of the Data Acquisition program.

5A.3 Correct Nonlinearity

The linearity has been calibrated but the grating image has not been corrected. Before calibrating the piezo sensitivities, correct for the non-linearity in the grating image in the Image Process menu.

In the Image Process menu, select Linearity Correction and agree to correct the non-linearity distortion of the grating image.

Enter (1,1) for the distortion factors. Then the linearity correction just found will be applied in both X0 and Y0 directions.

When the correction is done, accept it and ask to correct pin distortion. The widths of the lines of grating should look linear.

Pin distortion correction will make the grating rows parallel (whereas nonlinearity correction made the spacing between rows constant). To perform a pin distortion correction you must "mark" two vertical rows using the mouse (these rows must pass through both the top and bottom lines of data). Put the mouse in the middle of the maxima of a grating row and click the left button. Repeat this at at least four different points on the same row, then press the right button to indicate that the first line has been marked. Repeat this procedure for a second line (it is best if these lines are as far apart as possible). The computer will then arrange the image to make the selected lines parallel.

5A.4 Tilt Correction

In order to calibrate the Z piezo you have first to tilt correct the grating image.

In the Image Process menu, select Tilt Correction.

Tilt correct the image in X, but not line-by-line, to third order.

5A.5 X and Y Calibration

Only one piezo direction is calibrated; the two directions are assumed to have the same piezo sensitivities.

In the Line Display menu, choose the Roughness option.

Use the cursor to draw a horizontal line along the grating, using the first button to start the line and the second to end it. Draw the line all the way across the image, so that it follows the center of a grating row. The more peaks you include, the more accurate your calibration will be.

Use the cursor in the same way on the Height Profile window to draw a line between grating peaks at the two ends of the cross section. When you draw the line, the distance between the peaks (X displacement) is displayed in the Coordinate Table in the center of the screen.

Determine the actual distance, knowing that the grating spacing is one micron. The distance displayed will be different if the X,Y piezo sensitivity is incorrect.

Calculate the fraction by which the measured distance differs from the actual distance.

5A.6 Z Calibration

The Z calibration is done using the Area Statistics option.

In the Roughness menu, select the Area Statistics option.

Use the mouse to draw a square box that includes four grating peaks and one grating minimum, exactly centered about the minimum, and agree to tilt correct the region. Do this near the center of the image.

Record the peak to valley distance in the Roughness Values window, and repeat for a total of five times.

Take the minimum value found in this way and subtract 80 Å. In this way the true grating height is measured; 80 Å is the contribution of the roughness of the grating surface.

Calculate the factor by which this differs from 2000 Å. It will differ from 2000 Å if the Z piezo sensitivity is incorrect.

5A.7 Changing the Piezo Sensitivities

To use the calibration, update the piezo sensitivities.

In the Set Up menu, select Extended Configuration.

Change the Z piezo sensitivity by the factor calculated above. For example, if the measured grating height was 3000 Å instead of 2000 Å, replace the Z piezo sensitivity with 2/3 its current value.

Change the X,Y piezo sensitivity by the factor calculated above. For example, if the measured grating spacing was 1.5 microns instead of 1 micron, replace the X,Y piezo sensitivity with 2/3 its current value.

Save the extended configuration. When you run the Data Acquisition program, the new piezo sensitivities will be loaded and future scans will be correctly calibrated.

5A.8 Correcting Previously Taken Images

If you calibrated the scanner after taking an image, you need to call up that image and change its parameters.

In the Image Processing program, load the image.

In the Set Up menu, select the Extended Configuration option.

Change the X,Y and Z piezo sensitivities as described in Section 5A.6 above. The Z scale will automatically be corrected, but the X and Y scales won't.

Select the Change Headings option in the Set Up menu, and change the X,Y scale according to the factor by which the X,Y piezo sensitivities were incorrect.

To correct non-linearity, select the Linearity Correction in the Image Process menu. If the Linear Factor was 1 when you took the image, then non-linearity in the X0 direction has already been corrected, with the previous linearity coefficients.

Enter (1,1) for the distortion factors if no linear correction was applied during data acquisition. Use (0,1), to correct only the Y0 direction.

In the Data Storage menu, re-save the image.

6 Image Processing Tutorial

Average-Height Tilt Correction in X

LIne By Line Tilt Correction in Y

Glitch Removal

Using the FFT

Wiener Filter Function

3-D Rendering

This chapter is a tutorial that introduces you to the most important functions of the Image Processing program. It will guide you through examples of glitch removal, tilt correction, removal of specific frequency components, and other common image processing techniques, using sample images. It will also show you how to generate 3-D rendered images.

This chapter is not exhaustive. Chapter 11 is a reference guide to the Image Processing program and describes all of its functions; you should refer to it for additional image and data processing, image display, and file handling procedures.

You will find the sample images on the floppy disk labeled "Tutorial." It includes the following image files:

+ **TSAMPLE01**
+ **TSAMPLE02**
+ **T_TILTX01**
+ **T_TILTY01**
+ **FSAMPLE01**
+ **TWIENER01**
+ **TGLITCH01**

Before you start the tutorial session, copy all of the files to your hard disk. Do this in the Shell Program. Put the Tutorial disk in the floppy disk drive and select the File Manager option. Set the storage device to `:,700,1` and press <Return>.

Choose the Select File option to see a list of files on the floppy disk. Choose the Copy option and copy all the files on the floppy to `:,700,0,2` (the hard disk drive).

Exit the File Manager menu to the Main Menu, and select Image Process option to run the Image Processing program. The system configuration parameters will be listed on the right hand side of the screen. If the Data Storage Device is not set to :,700,0,2 then you need to reset it. To do so, select the Set-Up menu option and then the Extended Configuration option. This lets you change the system configuration parameters. Use the cursors to select the Data Storage Device and type in the new setting.

6.1 Average-Height Tilt Correction in X

Many images acquired using STM or SFM require further tilt or curvature correction. The curvature associated with the image is mainly due to two factors. If the sample is not mounted flat with respect to the scan plane, there may be some tilt that cannot be removed electronically. Also, because a tube scanner is used, all large scans will show some curvature due to geometric factors. Tilt correction in both the X and Y directions can be helpful for many images, though very small (atomic scale) images will not require it.

For this exercise use the TSAMPLE01 image on the system hard disk. This is an SFM image of graphite with a scan size of about 10 μ x 10 μ. This image was taken without any real-time curvature correction, so it appears bright on both sides. (Real-time curvature correction is applied by setting Tilt Power to 3 in the Display Options menu of the Data Acquisition program before taking an image.)

Load this image by selecting Load from the Main Menu, entering TSAMPLE01 and pressing <Return>. To perform the tilt correction, select the Image Process menu option and then Tilt Correct.

You will be asked, TILT CORRECT X OR Y AXIS (X/Y) <X>? Press <Return> to select tilt correction along the X-axis. Then you will be asked, X AXIS TILT - LINE BY LINE CORRECTION? <N> Press <Return> to perform an average-height tilt correction.

When asked, USE THE FULL RANGES IN BOTH X AND Y? <Y>, press <Return> to use the whole image in calculating the correction. The curve displayed on the right-hand side represents the average X-scan for the image.

Next you will be prompted, ENTER POWER OF LEAST SQUARE FIT. (1-9) <1>. You need to enter the order of polynomial for the least squares fit. Enter 3 for a third-order polynomial fit, then press <Return> to continue. The third-order polynomial is plotted in red on top of the first curve.

When asked, SUBTRACT RED CURVE? <Y>, press <Return> to perform the correction. When the correction is completed, the tilt corrected image will appear on the right side of the screen. The tilt corrected image now looks much flatter in the X direction than it did before. (Ignore the glitches on the image for now.)

When asked, ACCEPT? <Y>, press <Return> to accept this image. To save it on the disk, select Exit, Data Storage, and Save; when asked to ENTER DATA NAME <TSAMPLE01>, enter CSAMPLE01 (for "corrected sample"), or another valid string of your choice, and press <RETURN>. It is a good idea to save image-processed data by a different name in order to preserve the raw data.

The image you have just saved should look exactly the same as the image on disk called T_TILTX01. To see the T_TILTX01 image, select Load Data. When prompted ENTER DATA NAME TO BE LOADED. <TSAMPLE01>, OR '.' TO TERMINATE, enter T_TILTX01 and press <Return>.

6.2 Line-by-Line Tilt Correction in Y

The dark band in the middle of the image TSAMPLE01 was created by changing the DC LEVEL on the Control Module while taking the data. Switching the DC LEVEL to HOLD creates a slowly changing DC signal superimposed on the data signal. This artifact was introduced intentionally to make the effects of line-by-line tilt correction in Y obvious. An average-height tilt correction in Y cannot remove the DC component in this image, since that procedure fits the DC component to a polynomial which is then subtracted from the data. You can try performing an average-height correction in Y; it is similar to the average-height correction in X described in Section 6.1.

If the image TSAMPLE01 is not currently displayed, load it from the hard disk. In the Main Menu, select Load Data. When prompted with ENTER DATA NAME TO BE LOADED. () OR '.' TO TERMINATE, enter TSAMPLE01 and press <Return>.

Select Exit, Image Process and Tilt Correct. When asked TILT CORRECT X OR Y AXIS (X/Y) <X>?, enter Y and press <Return>. When asked, Y AXIS TILT - LINE BY LINE COMPENSATION? <N>, enter Y and press <Return> to select line-by-line correction. When asked USE THE FULL RANGES IN BOTH X AND Y? <Y>, press <Return> to use the whole image to calculate the curvature correction. Along each horizontal line, the average Z value along that line is subtracted from the Z value at each point. After a few seconds, the corrected image will appear on the right side of the screen. Notice that the dark band has disappeared.

When asked ACCEPT? <Y>, press <Return> to accept this image. To re-save it on disk, select Exit, Data Storage, and Re-Save. When asked, RE-SAVE "TSAMPLE01:, 700,0,2" <Y>?, enter Y and press <Return>.

The image you have just saved should look exactly like the image on disk called T_TILTY01 if you previously tilt corrected the image in X as described in Section 6.1. To look at the image TILTY, select Load Data. When prompted to ENTER DATA NAME TO BE LOADED. <TSAMPLE01>, OR '.' TO TERMINATE, enter T_TILTY01 and press <Return>.

6.3 Glitch Removal

This exercise demonstrates the use of glitch removal routines available in the Remove Glitch menu. To perform glitch removal on the TSAMPLE01 image, load that image if it is not currently displayed. Select Load Data, and when asked ENTER DATA NAME TO BE LOADED.<T_TILTY01> OR '.' TO TERMINATE, enter TSAMPLE01 and press <Return>. Then select Exit, Image Process, and Remove Glitch.

The TSAMPLE01 data appears in three different locations on the screen. The large image on the left side of the screen is the working area where you perform the glitch removal. The image on the top right corner is the original image, and below it is the image showing any changes that have been made.

To perform glitch removal one pixel at a time, select Average Vertical and move the red cursor to X, Y position (7,66). Hold down the first mouse button and drag the cursor to location (40,66). You will notice that the glitch has just been removed. At every point over which the cursor moved, the Z value has been replaced by the average of the values of its vertical neighbors. If you have accidentally removed good data, you can restore it by pressing the second mouse button.

The Average Horizontal function replaces the Z value at a point with the average of the values of its horizontal neighbors. To use this function, select Average Horizon and move the cursor to X, Y position (45,97). Then hold down the left mouse button and drag it to location (45,100). Glitches along the line will be removed.

The Average Line function replaces the Z value at every point on a horizontal line with the average of the values of its vertical neighbors. It is the same as the Average Vertical function but corrects an entire horizontal line at one time.

Select Average Line and move the cursor so that the Y position is 70, then click the left mouse button once. The horizontal glitch is removed completely. Repeat this procedure at Y = 84, 85, 86, 87, 118 and 117.

The Offset Line function removes a low frequency component that is superimposed onto good data. This function requires you to select a reference line that has characteristics similar to the offset line but without the low frequency component. The noisy line and reference line are both fitted to

polynomials; the difference between the polynomials (the DC noise contribution) is subtracted from the noisy line.

Select Offset Line, and when prompted with `POWER OF POLYNOMIAL <3>?`, enter `3` and press <Return>. Then the reference line and noisy line will be fit to third-order polynomials. Move the cursor to position Y=119 and click the left mouse button once to select this as the reference line. `REFERENCE SELECTED` will appear at the bottom of the screen. Now move the cursor to location Y=118, and press the left mouse button once. Notice the change in gray scale for this line from light to slightly darker. Repeat this procedure for the following Y locations (remember, you need to re-select a reference line each time you want to correct an offset line):

Y Reference line	Y Offset line
118	117
117	116
116	115
115	114
114	113
113	112
112	111

To exit the Glitch Removal menu, select Exit, and when prompted with `FINISHED <Y>`, press <Return>. To save the corrected image, select Exit, Data Storage, and Re-Save. When asked, `RE-SAVE "TSAMPLE01:,700,0,2" <Y>?`, press <Return>. The TSAMPLE01 image should look the same as the image on disk named TGLITCH01. To look at this image, select Load Data. When asked, `ENTER DATA NAME TO BE LOADED <TSAMPLE01> OR '.' TO TERMINATE GLITCH_REM`, type `TGLITCH01` and press <Return>.

6.4 FFT: Removing Specific Components

The FFT routine is useful for removing specific frequency components from the image data or filtering the data. This function Fourier transforms the data to the frequency domain where unwanted frequencies can be removed. An inverse Fourier transformation generates the corrected image. For this example use the TSAMPLE02 image, an STM image of graphite atoms with random noise in the Y direction.

First load the TSAMPLE02 image from disk by selecting Load Data and typing `TSAMPLE02` at the prompt. Then select Exit, Image Process, and FFT/Filter. After a few seconds the power spectral density of the Fourier transform of the image data will be displayed in the middle of the screen. The horizontal axis corresponds to Fourier components in the X0 scan direction, and the vertical axis corresponds to Fourier components in the Y0 scan direction. The noise spectrum along the X0-axis is usually 1/f and noise along the Y0-axis is usually random.

The prompt `ENTER AMP FOR GRAY-SCALE DISPLAY. (0 FOR EXIT) <.2>?` refers to the gray scale used in displaying the Fourier transform. The gray-scale display makes it easy to distinguish between signals of different intensities. Enter `0.1` and press <Return>. You can try different gray-scale values to see the effect on the Fourier transform display. To proceed, enter `0` and press <Return>.

Next you will be asked, `REMOVE SPECIFIC COMPONENT? <N>`. Enter `Y` and press <Return> to remove noise components from the data. You will be able to see the six peaks corresponding to the axes of symmetry of the graphite surface. There is also a band running vertically through the center of the Fourier transform. Place a window to include as much of this

band as possible without including any of the six principal peaks of the spectrum. Use the first mouse button to change the window size and second mouse button to accept the window. When you are asked ANOTHER? <Y>, enter N to finish.

You will be asked if you want to apply the Wiener filter to the data. Bypass this routine for now; it will be used in the next section. When asked, APPLY FILTER FUNCTION? <Y>, enter N and press <Return>. When prompted to ENTER AMP FOR GRAY-SCALE DISPLAY (0 FOR EXIT) <.1>? enter 0 and press <Return>. When asked ACCEPT? <Y>, press <Return>. The screen will then read, INVERSE FOURIER TRANSFORMING. PLEASE WAIT...

The image display on the lower right corner of the screen is the image after the inverse Fourier transformation. If you have removed the high frequency Y noise correctly, there should not be any noise apparent in the image. Press <RETURN> when asked ACCEPT? <Y>. Then select Exit, Data Storage, and Save. Save this image under a new filename, TUFILTER2, so that the original image can be used with the Wiener filter in the next section.

The corrected image should look like the image on the disk named FSAMPLE01. To see this image, select Load Data. When asked to ENTER DATA NAME TO BE LOADED <TUFILTER2>, OR '.' TO TERMINATE, enter FSAMPLE01 and press <Return>. If this image looks different from yours, try repeating this exercise and removing different frequency components to see the effect on the image.

6.5 FFT: Wiener Filter Function

The Wiener Filter function is useful in removing high frequency noise from the data. It is similar to a low-pass analog filter in an electrical circuit. In order to apply the Wiener filter function to the data, the data must first be Fourier transformed. Use the image TSAMPLE02 for this example.

Select Load from the Main menu. When asked to ENTER DATA NAME TO BE LOADED <FSAMPLE01> OR '.' TO TERMINATE, enter TSAMPLE02 and press <Return>. Then select Image Process and FFT/Filter.

When asked to ENTER AMP FOR GRAY-SCALE DISPLAY (0 FOR EXIT) <.2>?, enter 0 and press <Return>. When asked, REMOVE SPECIFIC COMPONENT? <N> press <Return>. When asked APPLY FILTER FUNCTION? <Y>, press <Return>. When prompted to ENTER FILTER STRENGTH. <1>, enter 25 and press <Return>. The screen will read: APPLYING FILTER FUNCTION. PLEASE WAIT...

The filter strength is related to the band-width of the filter. If the strength is too great the Fourier transform will become flat and the entire image may even be filtered away.

When asked, ACCEPT? <Y>, enter Y and press <Return>. The screen will now read: INVERSE FOURIER TRANSFORMING. PLEASE WAIT...

The image that appears on the lower right corner should appear much less noisy than the original image. When asked ACCEPT? <Y>, enter Y and press <Return>. To re-save this image, select Exit, Data Storage, and Re-Save. Press <Return> when asked RE-SAVE "TSAMPLE02:,700,0,2" <Y>?

This image should look like that stored on disk labeled TWIENER01. To see that image, select Load Data. When prompted to ENTER DATA NAME TO BE LOADED <TSAMPLE02> OR '.' TO TERMINATE, enter TWIENER01 and press <Return>.

6.6 3-D Rendering

This exercise will guide you step-by-step through the process of rendering the FSAMPLE01 image in three dimensions. Select Load from the Main Menu, and when asked to ENTER DATA NAME TO BE LOADED <FFT> OR '.' TO TERMINATE, enter WFTSAMPLE and press <Return>.

Change the image color from gray to gold by selecting Set-up, Set Color, Gold, Exit, and Exit again.

Then select the Enhanced Display menu to perform a 3-D render. Select Height Image to prepare the data for 3-D rendering data. Then select Curvature Image to prepare the curvature rendition, i.e. edge-enhancement data. The screen will read: CALCULATING CURVATURE. PLEASE WAIT... Then it will read: CALCULATE STANDARD DEVIATION. PLEASE WAIT... When asked to ENTER ST. DEV AND OFFSET. <2.5,0>?, press <Return>. When asked, ACCEPT/TRY AGAIN/QUIT? (A/T/Q) <A>, press <Return>.

Select Shade Image to prepare shade-enhanced data. Press <Return> when prompted to ENTER THE DIRECTION OF LIGHT SOURCE: Theta, Phi (0..90,0..90) <50,90>? Press <Return> when asked, USE FULL GRAY SCALE? <N>. The screen will read: CALCULATING SHADE DATA. PLEASE WAIT...

Select Combine Data to combine the enhanced images. When prompted, AMOUNT OF HEIGHT, CURVATURE AND SHADE (0..1,0..1,0..1) <0,0,0>? type 0.8,0.1,0.1. The screen will read: COMBINING DATA. PLEASE WAIT...

To generate the 3-D rendered image select 3-D Render, then Generate Render. You will be prompted to SELECT RENDER DATA. Select Combine Render, or, if you want to generate the 3-D rendered image using the height data, select Height Render instead. When asked to ENTER Z SCALE Unit. <100>? press <Return>.

You can print out the 3-D rendered image if you have a LaserJet printer or a Mitsubishi video printer. To print with a Mitsubishi printer, select R-size and set the render size to 0.7 before generating the 3-D rendered image. Otherwise the image will not fit on one page. You can also use the Save To File function to save the rendered image to disk. Realize that rendered images occupy a lot of disk space.

Part II
Reference Guide

The following chapters provide a functional description of every hardware component and software option of PSI's STM-SA1 and SFM-BD2.

7 Mechanical Components

The main mechanical components are the microscope base, the heads, and the optical microscope. The base and the optical microscope are used by both the SFM and STM systems, while the microscope heads are specific to each system.

7.1 Microscope Base

The base is shown in Fig. 7-1. It houses the sample scanner, three approach screws, and connections to the CCU and head. It also provides some vibration isolation.

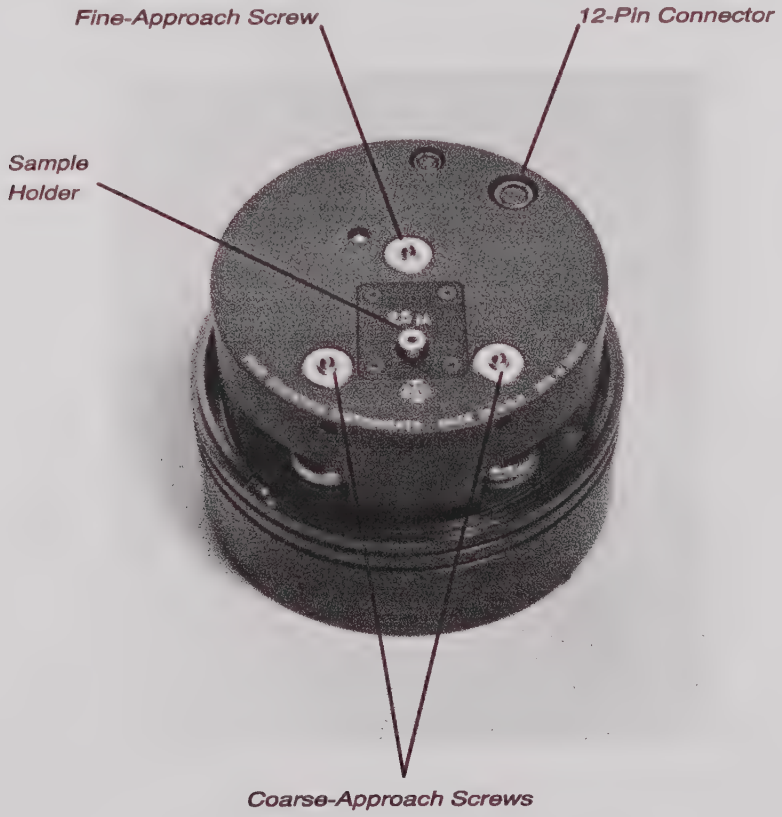


Fig. 7-1 Microscope Base

7.1.1 The Sample Scanner

The sample scanner is a piezoelectric tube housed in a plug-in unit, illustrated in Fig. 7-2. A sample holder is attached to the top of the scanner. Sample stubs fit into the sample holder, and are held in place with a set screw. (The appropriate allen wrench is included in

your tool kit.) The sample is scanned back and forth and the tip is held stationary; the scanner also moves the sample vertically to adjust the tip-sample distance.

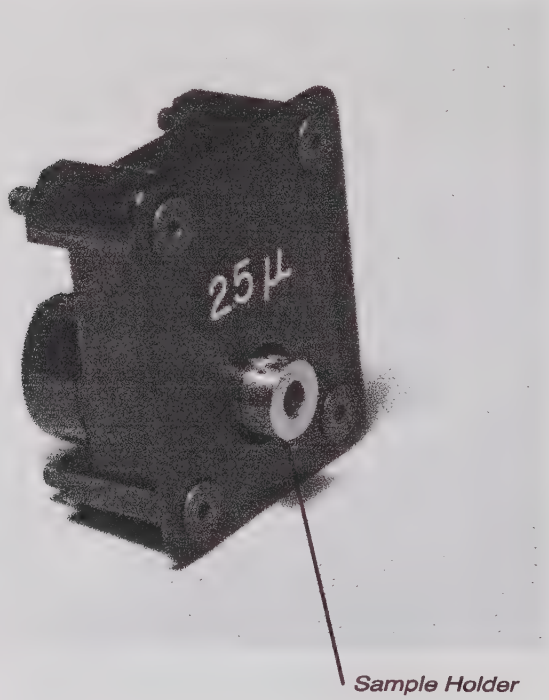


Fig. 7-2 Plug-in Scanner

7.1.2 The Approach Screws

The top face of the base contains three ball-screws. The two front screws are coarse-approach screws turned by hand with the knurled knobs, and the back screw is driven by a stepper motor controlled by the electronics. The translation stage which is attached to the microscope head rests on these three screws.

7.1.3 Connections

The circular 12-pin connector accepts the complementary connector from the microscope head. The port on the bottom side of the base is connected to the CCU with a 25-pin interface cable. On the bottom of the base are exposed traces with high voltage. An additional connection on the top of the base is for future use. If you should ever lift up the top part of the base, you will expose wires connecting the top and bottom parts of the base. When you replace the top of the base, simply coil these so that the top of the base will not rest on them.

7.2 STM Head

The STM head, shown in Fig. 7-3, has a tip holder, preamp, and 12-pin connector that plugs into the base. The tip holder is rotatable so that the tip can be angled when the optional 1000X optical

microscope is used. The translation stage (described in Section 7.4 below) attaches to the STM head with four bolts.

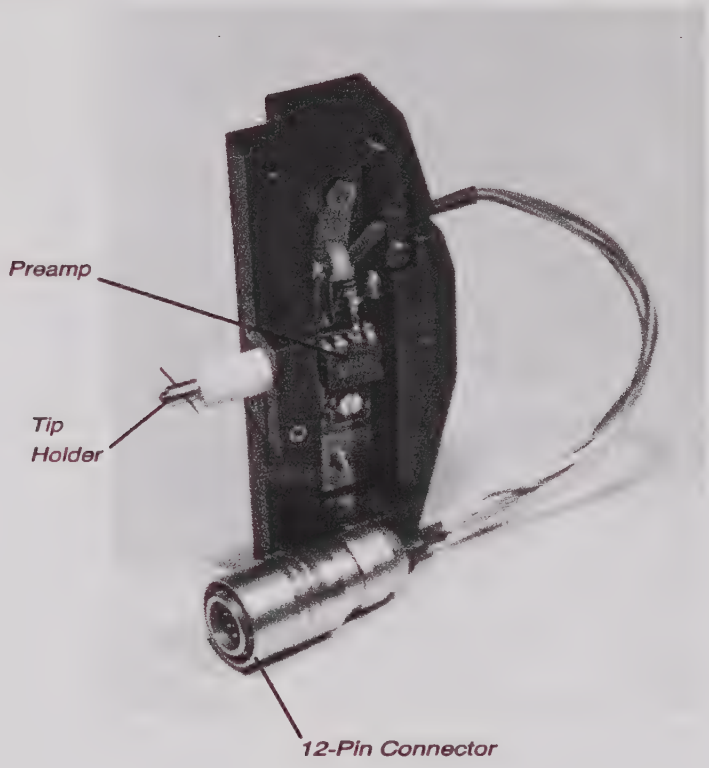


Fig. 7-3 STM Head

7.3 SFM Head

The SFM head, illustrated in Fig. 7-4, has a Microlever mount, laser, steerable mirror, position-sensitive photodetector (PSPD), preamp, and 12-pin connector that plugs into the base.

A chip with Microlevers is held in place with a clip (the chip holder) in the Microlever mount as shown in Fig. 7-5. The preamp includes an attenuator for the laser (potentiometer), which is accessible to the user on the side of the head through the laser warning label. This potentiometer has already been set. We recommend that it never be touched, but if it becomes necessary to do so, consult PSI first. It is provided so that the laser power can be increased if it is too low. When properly set, A+B will read one-half full scale on the SFM Control Module with the laser light all reflected off the Microlever.

Light from the laser diode reflects off the mirror and can be steered onto the end of the Microlever with the mirror-steering screws. It is reflected up to the PSPD, which can be moved in and out with the PSPD positioning screw. The PSPD is actually two photodetectors positioned very close to each other, called A and B. The preamp board controls the current supply to the laser diode and amplifies the signal of the PSPD. Its output includes the following signals: A+B, A-B, 10(A-B), and 100(A-B). The translation stage (described in Section 7.4) attaches to the SFM head.

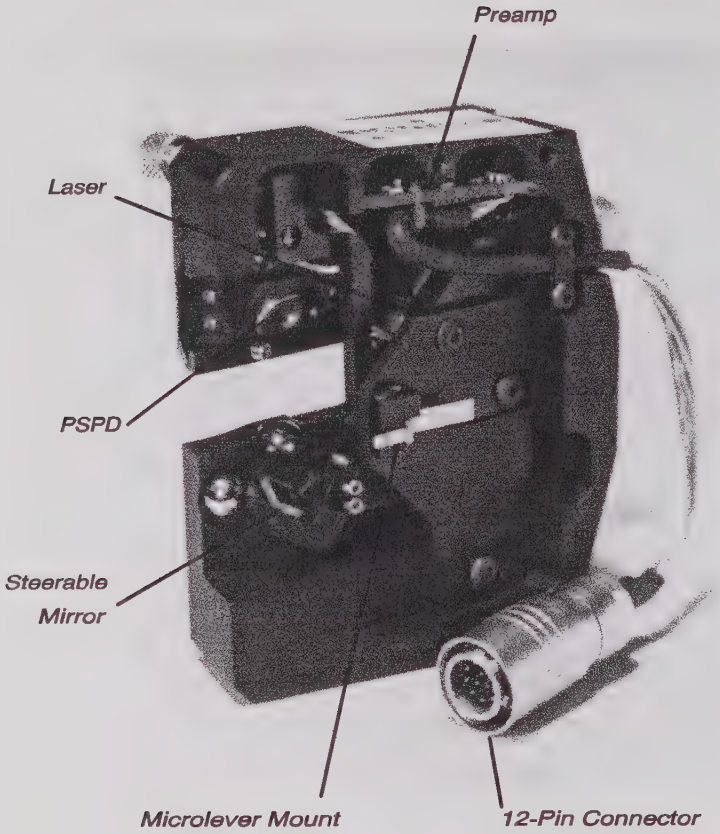


Fig. 7-4 SFM Head

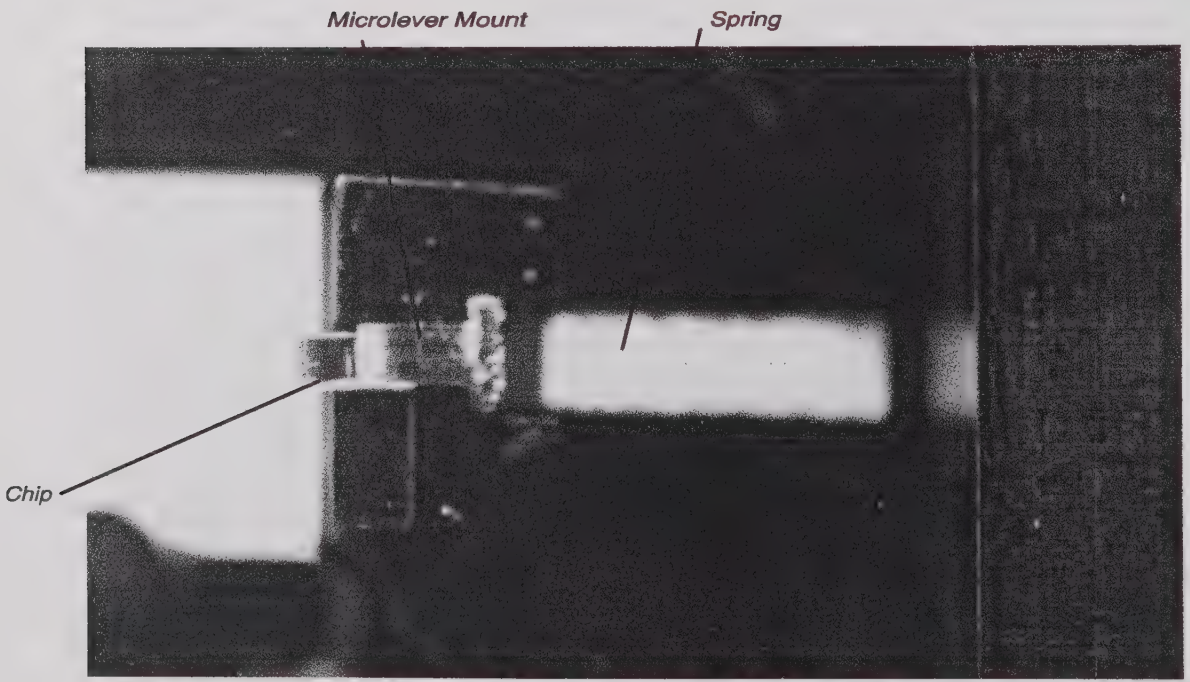


Fig. 7-5 Chip with Microlevers in Mount

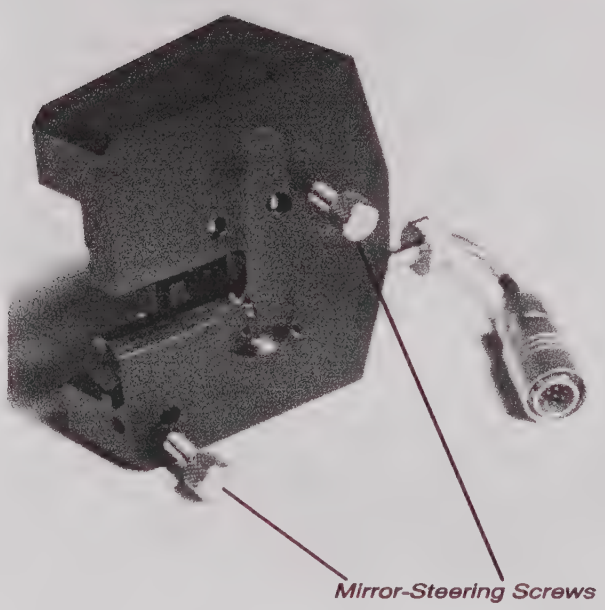


Fig. 7-6 SFM Head Showing Mirror-Steering Screws

7.4 Translation Stage

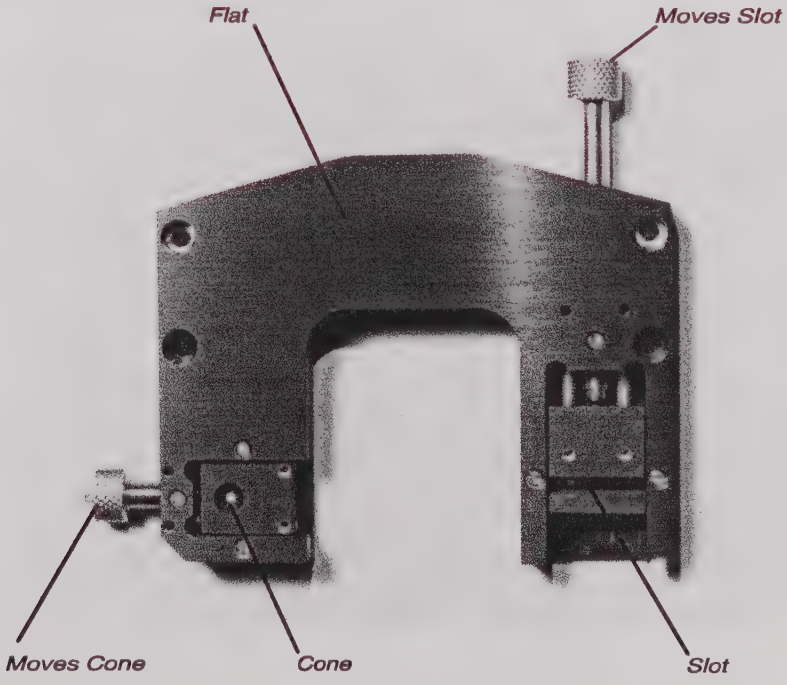


Fig. 7-7 Translation Stage

The translation stage, shown in Fig. 7-7, is used with both the STM and SFM heads. It sits on the three ball-screws on the base in a kinematic mounting system. A cone fits over the right coarse-approach screw, and a slot fits over the left coarse-approach screw. A flat surface rests on the fine-approach screw. In this way positioning is reliable and repeatable. Two coarse-translation knobs control the movement of the translation stage. These knobs control the lateral position of the tip relative to the sample, and thus the region that will be scanned. Their range is 5mm by 5mm.

7.5 120X Optical Microscope

The 120X optical microscope is used for observation of the sample and tip during sample approach. It should be used with a fiber optic or gooseneck lamp. A zoom lens is attached to the objective.

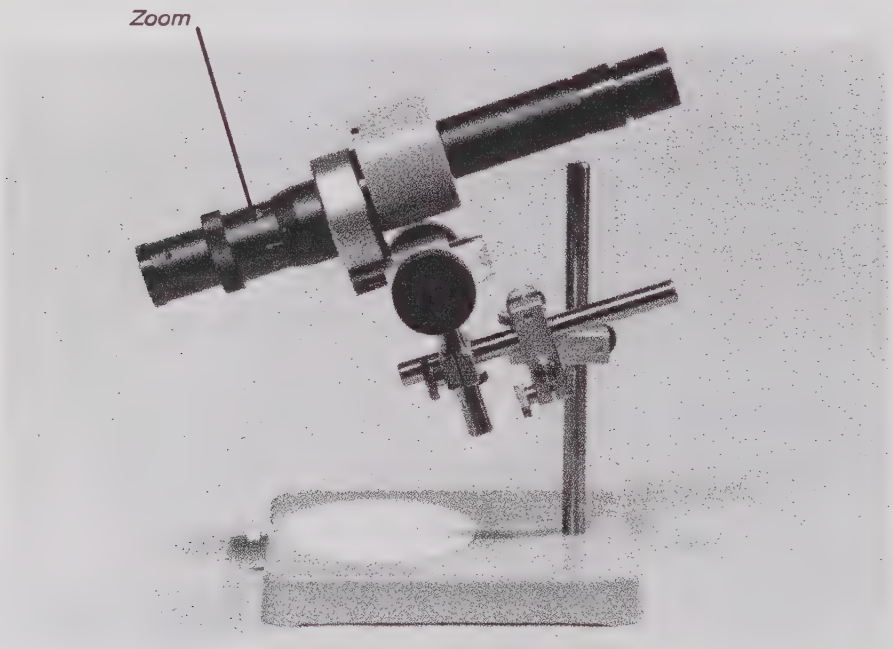


Fig. 7-8 120X Optical Microscope

8 Electrical Components

The main electrical components are the Central Control Unit (CCU) and the two Control Modules. The CCU is shared by the STM and SFM systems.

8.1 Central Control Unit

The Central Control Unit (CCU) is used for all of the scanning microprobe systems offered by Park Scientific Instruments. It houses the analog electronics for the scan control, stepper motor, and signal monitor. It also houses a comprehensive digital interface board which is controlled by the host computer (HP workstation) through an IEEE488 GPIB connector. The interface board has on-board memory and a microprocessor so that the host computer can be devoted to operations like graphics display rather than control functions. The CCU also houses connections between the microscope base and the Control Module.

The Central Control Unit is logically designed to provide easy manipulation of the control parameters. The front panel contains the control knobs, and the rear panel houses the various signal connectors.

8.1.1 SCOPE MONITOR Panel

The triangular ramp signal for the X0-scan is on continuously so that one line of data is always displayed on the CCU scope. This real-time display of the data allows the user to change the scan and feedback parameters and immediately see the effect on the data.

The **DETECTOR SIGNAL/IMAGE DATA** toggle switch determines which signal is displayed on the scope. When it is toggled to DETECTOR SIGNAL, the signal from the detector (tunneling current in STM, A-B in SFM) is displayed. In the case of STM, if the scope **GAIN** is maximum, with the TUNNELING CURRENT switch toggled up on the STM Control Module, the calibration is 1 nA/division, and with it toggled down the calibration is 0.1 nA/division. When IMAGE DATA is selected, the scope displays the data that is read by the computer. The data source is set on the IMAGE ACQUISITION panel of the Control Module. When the SOURCE switch is toggled to Z (for constant-current or constant-deflection mode) the scope shows the signal applied to the Z piezo, and when toggled to ln(I) or A-B (for constant-height mode) the scope shows the error in the feedback loop.

8.1.2 SCAN CONTROL Panel

The SCAN CONTROL panel lets you control the signal that is applied to the piezoelectric scanner. A triangular ramp signal is generated by the computer, and the amplitudes of the signals going to the X and Y piezos are controlled on this panel. This panel also lets you change the DC offset voltages applied to the X and Y piezo elements.

SCAN SIZE: The SCAN SIZE panel controls the scan range of the X and Y piezos by setting the fraction of the ramp signal that is applied to the piezos. The **X0 AXIS** and **Y0 AXIS** potentiometers control the scan range of the piezos; the X0 axis is scanned continuously, and the Y0 axis is scanned only when the computer initiates an image. The

MULTIPLIER sets the range of the X0 AXIS and Y0 AXIS potentiometers. With MULTIPLIER set at 100, the potentiometers cover the full range of the scanner. With the MULTIPLIER set at 10, the largest scan size is one-tenth the full range, and set at 1 the largest is one-hundredth the full range. Changing the MULTIPLIER causes an abrupt change in the tip/sample junction, so the SCAN SIZEs should be reduced to zero before changing the multiplier, to protect the tip.

SLOPE: The SLOPE panel lets you correct for sample tilt relative to the scan plane. When the sample is sloped with respect to the scan plane, the line display on the X-Y display monitor will not be horizontal, the A/D converter may not be used efficiently, and feedback may not be efficient. The SLOPE potentiometers can make the line scans horizontal in most cases. The slope correction works by adding a fraction of the X0 or Y0 scan signal to the Z-piezo signal. This leaves the feedback system to correct only for local sample topography, thereby improving the system response. The **X0 AXIS** potentiometer tilts the trace on the scope, since the X0 axis is that which is constantly scanned. The effect of the **Y0 AXIS** potentiometer will be apparent only when you take an image, since then the sample is scanned in the Y0 direction.

ROTATION: The ROTATION switch lets you select the scan direction (X0 axis). When the ROTATION is set to 0, the X0 axis corresponds to the X piezo; when it is set to 90°, the X0 axis corresponds to the Y piezo. One use of this feature is with drastically tilted samples. Rotation allows the user to find a scan direction which minimizes tilt. Because changing the ROTATION causes an abrupt change in the junction condition, you should reduce the SCAN SIZEs to zero before using ROTATION. The scan position is rotated about the scan center and therefore does not rotate the X and Y offsets.

DC OFFSET: The DC OFFSET panel lets you change the DC voltages applied to the X and Y piezos. The **X10 X AXIS** and **Y AXIS** potentiometers span the full scanner range, and the **X1 X AXIS** and **Y AXIS** potentiometers span one-tenth of the full scanner range. Changing the DC OFFSET by a large amount causes an abrupt change in the junction condition, so you should switch SLOW FEEDBACK to WDRW beforehand.

CLIPPING: The CLIPPING lights will go on whenever either the X or Y piezo is at the end of its range.

8.1.3 SCANNER MONITOR Panel

The SCANNER MONITOR panel has a bar graph showing the position of the three piezo elements. A switch lets you select which piezo element is monitored. With the switch set to Z, the bar graph will be replaced either by a green LED at the right end when the tip is fully extended or a similar LED at the left end for the fully withdrawn state. When feedback is active, and you want to center the piezo in its range, move the tip forward or backward with the stepper motor and the COMP/MAN switch set to MAN.

8.1.4 SAMPLE APPROACH Panel

The SAMPLE APPROACH panel lets you control the stepper motor that drives the fine approach screw in the base. The **CONT/PULSE** switch and **POWER** potentiometer are for use with the UHV STM only. The four green LEDs indicate the status of the four coils in the stepper motor. The **COMP/MAN** switch selects whether the stepper motor will be controlled through the computer (COMP) or manually on the CCU (MAN). It must be set on COMP for a computer approach or whenever the Move Sample menu of the Data

Acquisition program is used. When it is set to MAN, you can move the stepper motor by toggling the **FWD/BWD** switch. FWD lowers the tip toward the sample, and BWD raises the tip away from the sample. The speed of the stepper motor is changed with the SPEED knob. If feedback is activated, you should switch SLOW FEEDBACK to WDRW before moving the stepper motor to protect the tip, especially with STM.

8.1.5 Rear Panel

The back panel houses the electrical connectors to and from the computer, the Control Module, and the microscope head.

The CCU is connected to the computer with a 4-meter HPIB cable. The CCU is connected to the Control Module and base with 25-pin interface cables.

Check that the CCU has been set for the correct line voltage.

8.2 STM Control Module

The STM Control Module houses the feedback electronics for STM and connectors to tap different signals. The TEMPERATURE panel is used with the UHV STM only.

8.2.1 TUNNELING Panel

The TUNNELING panel lets you control the tunneling parameters. The **VOLTAGE** potentiometer lets you set the magnitude of the bias-voltage applied to the STM tip. When the VOLTAGE switch is toggled up, the range of this potentiometer is 0.1 to 10 V. When the switch is toggled down, the range is 0.01 to 1 V.

The **CURRENT** potentiometer lets you set the magnitude of the tunneling current around which feedback operates. When the CURRENT switch is toggled up, the range of this potentiometer is 0.1 to 10 nA. When it is toggled down, the range is 0.01 to 1 nA. This toggle switch determines the order of magnitude of the current signal displayed on the scope of the CCU and used by the computer during auto approach.

8.2.2 Z-FEEDBACK Panel

The Z-FEEDBACK panel is common to both STM and SFM Control Modules. It lets you adjust feedback parameters.

The **FAST FEEDBACK GAIN** and **TIME CONSTANT** refer to the gain and time constant of the feedback loop. They must be optimized for good images. The higher the gain, the better feedback can track features. The lower the time constant, the faster feedback can respond to features. However, feedback systems oscillate when the gain is too high or time constant too low. Feedback is optimized when the GAIN and TIME CONSTANT are set just below the oscillation condition. For constant-height imaging, feedback should be disabled by setting the GAIN low (around 0.2) and TIME CONSTANT high (10).

The **SLOW FEEDBACK SELECT** switch lets you activate and deactivate feedback. When it is set to **COMP**, the feedback is partially deactivated and the computer controls

the extension of the Z piezo. This setting is used only for computer approach. When set to **WDRW**, the Z piezo is fully contracted so the sample is pulled away from the tip. When it is set to **AUTO**, feedback is activated and the Z piezo is extended or contracted until the set tunneling current is detected. This setting is used for data acquisition. When it is set to **MAN**, you can control the extension of the Z piezo with the potentiometer manually. To have maximum manual control, turn off feedback by setting the FAST FEEDBACK GAIN to minimum.

8.2.3 IMAGE ACQUISITION Panel

The IMAGE ACQUISITION panel lets you control various parameters outside the feedback loop. The **SOURCE** switch determines which signal is displayed on the CCU scope and used by the computer for image generation. When it is toggled to **Z**, the signal applied to the Z piezo is the data signal. This setting is used for constant-current mode. For this mode, FAST FEEDBACK GAIN must be high and the TIME CONSTANT small so that feedback can respond to every change in the surface contour. When it is toggled to **ln(I)**, the error in the feedback loop is the data signal. This setting is used for constant-height mode. For this mode, FAST FEEDBACK GAIN must be low and the TIME CONSTANT large to prevent feedback from responding to every change in contour, thus maximizing the error in the feedback loop. The signal is then read as changes in the tunneling current.

The **DC LEVEL** switch determines the time constant for DC blocking. When it is toggled to **TRACK**, data with a frequency lower than 0.1 Hz are cut off, and when it is toggled to **HOLD**, the cutoff is 0.01 Hz. Generally, sample tilt in the Y0 direction will appear in images taken with the switch on HOLD, and will not appear in images taken on TRACK. HOLD is useful for eliminating filtering artifacts due to DC blocking.

The **GAIN** switch determines the degree of amplification of the image signal before going through the A/D converter. To use the A/D converter most efficiently, the signal should be amplified as much as possible without saturating the A/D converter. When GAIN is set on 10 or 100 the signal is 10 or 100 times, respectively, greater than when it is set on 1.

8.2.4 POWER Switch

The POWER switch is used with the UHV STM only.

8.2.5 Rear Panel

The rear panel of the STM Control Module has a 25-pin interface connection for the Central Control Unit. There are four BNC connectors. V MOD IN lets you apply a modulated bias-voltage to the tip, for dI/dV measurements. Z MOD IN lets you add modulation to the voltage on the Z piezo for dI/dz measurements. I OUT lets you monitor the detector signal and input it into a lock-in amplifier. LOCK-IN IN lets you input a lock-in signal so that the computer can measure dI/dV or dI/dz. External power is for use with the UHV STM only.

8.3 SFM Control Module

The SFM Control Module houses the feedback electronics and laser power.

8.3.1 BEAM MONITOR Panel

The meter monitors the signals from the preamp and the error in the feedback loop. The PSPD in the SFM head has two halves, A and B. The preamp outputs four signals: A+B, A-B, 10(A-B), and 100(A-B).

With the **METER** switch set at **A+B** the meter shows A+B, the full laser power reaching the detector. This power is a maximum when the laser beam hits the center of the Microlever, so this setting is useful during alignment of the laser beam. Typically the maximum A+B can be is half of full scale. This can be verified by putting a mirror in place of a Microlever and measuring A+B.

When the METER switch is set to **A-B**, the meter shows a multiple of A-B, determined by the setting of the MULTIPLIER switch in the FORCE panel. With the MULTIPLIER set at 1, the meter shows 100(A-B), and with it set at 100, the meter shows A-B. Deflection of the Microlever will appear as a deflection of the meter needle.

When the METER switch is set to **ERROR**, the meter shows the error in the feedback loop. This setting is useful when setting the force before computer approach. Before an approach, the Microlever is undeflected so the error will show the set deflection. If feedback is activated, it will strive to make the error zero.

The **NULL** potentiometer is used as a fine adjustment to zero A-B, thereby compensating for any offset in A-B caused by the mechanical adjustment of the photodetector made on the head.

8.3.2 FORCE Panel

The FORCE panel is used for setting the Microlever deflection for feedback operation. The **SETTING** knob sets the deflection. The order of magnitude of the deflection is set with the **MULTIPLIER** switch, and the sign is set with the toggle switch. When the switch is toggled up, the set deflection is away from the sample. When it is toggled down, the set deflection is toward the sample. For an approach, the switch must be toggled up. After approach the switch can be toggled down; at this point the lever is deflected toward the sample, with this bending force counteracted by a surface viscous force arising from ambient humidity.

8.3.3 Z-FEEDBACK Panel

The Z-FEEDBACK panel is common to both STM and SFM Control Modules. It lets you adjust feedback parameters.

The **FAST FEEDBACK GAIN** and **TIME CONSTANT** refer to the gain and time constant of the feedback loop. They must be optimized for good images. The higher the gain, the better feedback can track features. The lower the time constant, the faster feedback can respond to features. However, feedback systems oscillate when the gain is too high or time constant too low. Feedback is optimized when the GAIN and TIME CONSTANT are set just below the oscillation condition. For constant-height imaging, feedback should be disabled by setting the GAIN low (around 0.2) and TIME CONSTANT high (10).

The **SLOW FEEDBACK SELECT** switch lets you activate and deactivate feedback. When it is set to **COMP**, the feedback is partially deactivated and the computer controls the extension of the Z piezo. This setting is used only for computer approach. When set to **WDRW**, the Z piezo is fully contracted so the sample is pulled away from the tip. When it is set to AUTO, feedback is activated and the Z piezo is extended or contracted until the set deflection is detected. This setting is used for data acquisition. When it is set to MAN, you can control the extension of the Z piezo with the potentiometer manually. To have maximum manual control, turn off feedback by setting the FAST FEEDBACK GAIN to minimum.

8.3.4 IMAGE ACQUISITION Panel

The IMAGE ACQUISITION panel lets you control the data being read by the computer. The **SOURCE** switch determines which signal is displayed on the CCU scope and used by the computer for image generation. When it is toggled to **Z**, the signal applied to the Z piezo is the data signal. This setting is used for constant-deflection mode. For this mode, FAST FEEDBACK GAIN must be high and the TIME CONSTANT small so that feedback can respond to every change in the surface contour. When it is toggled to **A-B**, the error in the feedback loop is the data signal. This setting is used for constant-height mode. For this mode, FAST FEEDBACK GAIN must be low and the TIME CONSTANT large to prevent feedback from responding to every change in contour, thus maximizing the error in the feedback loop. The signal is then read as changes in the A-B.

The **DC LEVEL** switch determines the time constant for DC blocking. When it is toggled to **TRACK**, data with a frequency lower than 0.1 Hz are cut off, and when it is toggled to **HOLD**, the cutoff is 0.01 Hz. Generally, sample tilt in the Y0 direction will appear in images taken with the switch on HOLD, and will not appear in images taken on TRACK. HOLD is useful for eliminating feedback artifacts due to DC blocking.

The **GAIN** switch determines the degree of amplification of the image signal before going through the A/D converter. To use the A/D converter most efficiently, the signal should be amplified as much as possible without saturating the A/D converter. When GAIN is set on 10 or 100 the signal is 10 or 100 times, respectively, greater than when it is set on 1.

8.3.5 LASER POWER Switch

The LASER POWER switch turns on power to the laser.

> **Warning:** To avoid laser damage to the eye, the laser power switch should be turned off when the SFM head is inverted for changing the Microlever or for any other reason. It should also be turned off when plugging or unplugging the head to increase the lifetime of the laser.

8.3.6 Rear Panel

The rear panel of the SFM Control Module has a 25-pin interface connection for the Central Control Unit. There are four BNC connectors. Z MOD IN lets you add modulation to the voltage on the Z piezo for dF/dz measurements. Z OUT lets you monitor the signal applied to the Z piezo. A-B OUT lets you monitor the detector signal,

and input it to a lock-in amplifier for dF/dz measurements. LOCK-IN IN lets you input a lock-in signal for imaging in Mode 5.

9 Shell Program

The Shell Program (AUTOST) boots up automatically when you turn on the computer. A menu like the one shown below will appear at the bottom of the screen. From it, you can run the Data Acquisition and Image Processing program as well as perform file-handling operations.

REPACK DISK	BACKUP/ RESTORE	CHANGE VERSIONS	IMAGE PROCESS	SPM DATA ACQ	FILE MANAGER	EXTND CONFIG	EXIT TO OS

9.1 Repack Disk

After repeated use of the hard disk drive, there will be sectors that are unused and fragmented. In particular, when you purge a file or load new software without first purging the old version there will be gaps in the disk. For more efficient utilization of the hard disk drive, it should be periodically repacked using this function. Files will be packed toward the front of the disk so that available space will be contiguous.

When you select this function you will be asked `Are you sure you want to repack the disk? <Y>`. Press <Return> if you want to repack it. You will then be asked `Enter mass storage specifier. Default is :CS80,700.` This refers to :,700,0,0 which is where software is stored. If you want to repack this drive, press <Return>. If you want to repack the drives where data are stored, type `:,700,0,1` or `:,700,0,2`. (The CS80 will be understood.) The files on the drive will be listed. Those that have been purged will have arrows next to them, and they will disappear when the disk is repacked. Before you repack the disk, purged files can be recovered using the utilities disk.

9.2 Backup/Restore

If you have a tape-drive backup, you can use this function to back up your hard disk drive. First put a tape into the drive. Loaded and Busy lights will go on. When the Busy light goes off and the sound stops, select Backup/Restore. Use the softkeys to make a selection. After the backup, wait for everything to finish and the busy light to go off. Then select Unload Tape. Wait until the Clear light goes on, and then push the black button below the tape to release the tape.

9.3 Change Versions

If you have several versions of a single program, you can use this function to change which one will be run. When you receive software upgrades, you will receive new versions of the Shell Program that will run the new versions of the software.

When you select this function, the current version will be indicated. Press <Return> to accept the current version, or type in the name of the new version. If you just want to use a program once, you can load it from the operating system and run it without calling it up from the Shell Program.

9.4 Image Process

Selecting this function exits the Shell Program to load and run the Image Processing program, IP*_*.

9.5 SPM Data Acquisition

Selecting this function exits the Shell Program to load and run the Data Acquisition program, SPM*_*.

9.6 File Manager

CHANGE DISK ADD	SELECT FILE	DELETE	COPY	DISK COPY		FORMAT DISK	EXIT

9.6.1 Change Disk Address

Selecting this function lets you change the address of the mass storage device accessed by the File Manager. You will get the message `Enter disk drive address. () <:CS80,700>`. The default is :,700,0,0, which is where the programs are stored. You can press <Return> to keep this address, or type in another. For most users, :,700,1 is the floppy address and :,700,0,1 and :,700,0,2 are the hard disk drive addresses.

9.6.2 Select File

Selecting this function will let you select and list files located in the active mass storage device. The symbol * can be used as a wildcard. Its function is identical to the symbol ? in MS-DOS. Wherever * is entered the computer will substitute any alpha-numeric character for it. For example, if you type *8909**01, all the files that contain 8909 on the second through fifth character and 01 on the eighth and ninth character positions of the file name will be listed.

9.6.3 Delete

Selecting this function will let you erase an existing file in the active mass storage device. When you select this function, you will be asked `Individual or All?`. If you select `A`, all the selected files will be deleted. If you select `I`, the computer will step through the files on the drive and inquire whether each should be deleted.

9.6.4 Copy

Selecting this function will let you copy files from the selected mass storage device to different destinations either collectively or individually. When you select this function you will be asked the target disk destination. If you ask to copy files individually (I), the computer will step through the files on the drive, inquiring whether each should be copied to the target disk. If you ask to copy all (A) selected files, they will be copied without individual inquiry. If a file already exists, you will be asked if you want to replace it.

9.6.5 Disk Copy

Selecting this function will let you duplicate a floppy disk with a single floppy drive. The computer reads all the files on the original disk into the buffer, then copies them all onto a target disk.

9.6.6 Format Disk

Selecting this function will let you format a floppy disk. You will be asked the floppy drive address; for most users it is :,700,1.

9.7 Extended Configuration

This function lets you view and change the system parameters. Similar menu options exist in the Data Acquisition and Image Processing chapters.

9.8 Exit to OS

This function stops the Shell Program and exits to the BASIC operating system.

10 Data Acquisition Program

This chapter describes the program which enables the computer to acquire data from the SPM system, control the scan parameters, perform some data manipulation, and save data. This chapter is intended to be a reference section describing in detail every function key of the SPM*_* program. The main sections of the chapter cover:

+ choosing the imaging mode and scan parameters
+ performing initial data manipulation operations
+ how the computer buffers data
+ enabling data acquisition
+ computer approach
+ data storage

You can load and run SPM*_* from the Basic operating system. To run it from the Shell Program, go to the System Menu and select SPM Data Acquisition. The CCU and laser power for the SFM module should be on when you run the program. The power switch for the STM module is used for UHV only.

To stop the program, push <Stop> or <Shift><Reset> and exit to the Basic operating system. Then rerun it by typing RUN after restarting the CCU and Control Module. You can also stop the program by selecting End Session, which will return you to the Shell Program.

This chapter discusses the current version of the program, SPM 12_2. The menu structure of the Data Acquisition program is shown in Figure 10-1. The menu options displayed at the bottom of the screen correspond to the function keys, f1 through f8. To exit a menu, push f8 in all cases. When you first run the program, the computer will initialize a scan on the electronics and start at the Main Menu:

SET UP	DISPLAY OPTIONS	DRIFT COMPEN	BUFFER DATA	TAKE DATA	MOVE SAMPLE	DATA STORAGE	END SESSION

10.1 Set Up Menu

SPM MODE	X-SCAN RATE			TAKE DATA	TIME DATE	EXTNDED CONFIG	EXIT

The Set Up menu lets you change different parameters related to different aspects of the Data Acquisition program. It controls the SPM mode, which is basically the number of pixels per image and the spectroscopic capabilities. The X-scan rate and spectrum rate are controlled here. The default parameters, such as date, time, piezo sensitivity, and mass storage device, can also be changed in this branch of the program. If this is your first time using the program, you should set the time and date. Before scanning, set the X scan-rate; before taking an image, set the SPM mode; if using Mode 6, set the feedback period (which appears as an option in place of Spectrum Rate). Use the Extended Configuration option to set the X, Y, and Z piezo sensitivities and data storage device. Before taking a spectrum, set the spectrum rate.

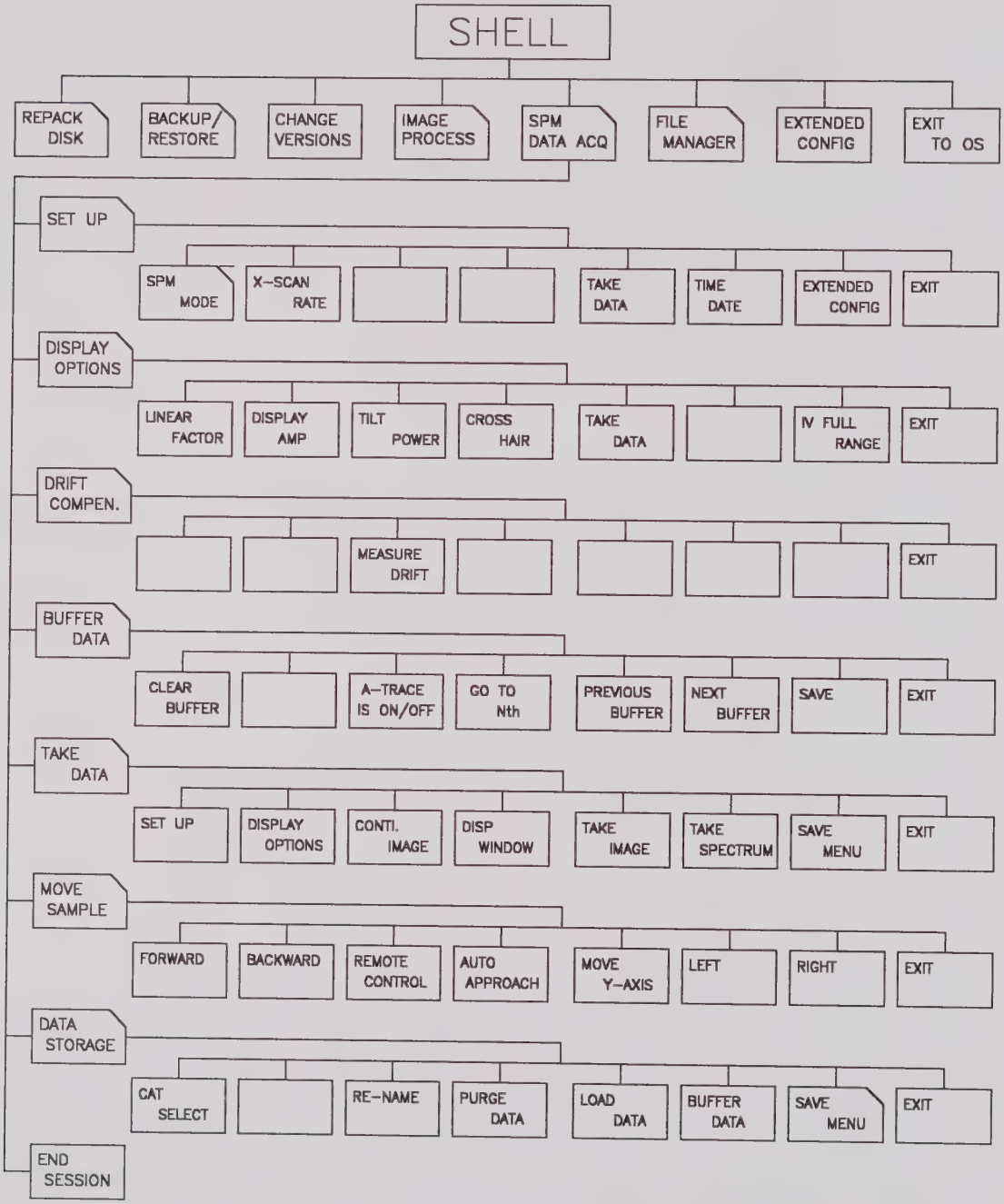


Fig. 10-1 Data Acquisition Menu Tree

When you exit the Data Acquisition program by choosing the End Session option of the Main Menu, all of these parameters are saved in the system configuration file. When you begin another session, the system configuration file will be loaded, and the parameters will be set to the saved values. Therefore, you do not need to set all of these parameters each time. You only need to change them if you change the piezo, data storage device, or the initial scan parameters.

10.1.1 SPM Mode Menu

MODE 1	MODE 2	MODE 3	MODE 4	MODE 5	MODE 6	WDRW	EXIT
128X128	256X256	512X512	D128X128	dI/D*	CITS	TIP	

This menu lets you select from among six imaging modes. It also lets you set the bias-voltage polarity if you are using STM, or if using SFM, the range of a force vs. distance curve. The mode must be set before taking images. The default mode is stored in the configuration file; it will be the SPM mode used when the configuration file was last saved. The modes differ in the number of data points taken per image, whether spectroscopy is performed, and how tip/sample junction parameters are set.

Mode 1 is the fastest and is appropriate when you want to have a quick view of the sample. After taking a Mode 1 image you can take spectra at up to eight different points in the scanned region, using the mouse to locate the points. Modes 2 and 3 are slower but provide higher resolution. Mode 4 is for STM only; it lets you take two images in parallel using different bias-voltages. Mode 5 is another spectroscopic mode where a differential signal can be used to generate the contrast in an image. For example, using a lock-in amplifier and modulating the bias-voltage, you can measure the local conductance, dI/dV vs. V, while simultaneously obtaining a constant-current image. This mode is also compatible with SFM. In Mode 6 every point in a topographic image will have an associated spectrum, taken in parallel.

If you are using STM, you can change the bias polarity when you set the SPM mode. +1 will bias the tip positive, and -1 negative. The bias-voltage is applied to the tip and the sample is grounded.

When you change the mode, the sample is withdrawn, and an X0 scan is re-initiated. You can therefore use this function to initiate an X0 scan on the electronics.

Mode 1 (128x128): Images are 128 by 128 data points. After taking an image you can take spectra at different points in the region scanned. This is the fastest mode, since the amount of data read into the computer is the least. Thus Mode 1 is useful for initial scans. Also, once you have taken a Mode 1 image with STM or SFM, you can select discrete points at which to take a spectrum. This is the only mode in which you can do this.

When you choose Mode 1 for SFM you will be asked what range of Z is desired for obtaining F vs. d curves. The full range is 0-10, which refers to the number on the SCANNER MONITOR on the CCU. Full range is rarely desired, since nonlinearities of the detector will dominate. You should pick a range that includes snap-back as well as the force used during imaging.

Mode 2 (256x256): Images will be 256 by 256 data points. You cannot take spectra with this mode.

Mode 3 (512x512): Images will be 512 by 512 data points. You cannot take spectra with this mode.

Mode 4 (D128x128): This mode is for use with STM only; it generates two 128 by 128 images of different bias-voltages in parallel. This mode can help to enhance the contrast between different materials by imaging their difference in local electronic structure. When you select this mode, you will be asked to `ENTER TWO TUNNELING VOLTAGE FACTORS TO BE ALTERNATED (-1..1,-1..1). <*,*>?` The bias-

voltage factors determine what fraction of the bias-voltage selected on the STM Control Module will be used. For example, if you select .5,-1, and the bias-voltage is set to 1 V, one image will be taken with bias-voltage .5 V and another at -1 V. It is a good idea to use 1 for one of the two scale values. Both images are taken in the same direction; the tip voltage is alternated for every scan line.

Mode 5 (dI/d*): This mode is used with STM and SFM to obtain simultaneous topographic and spectroscopic images (dI/dV or dI/dz at a fixed bias-voltage, or dF/dz for SFM). A pair of A/D channels are read by the computer alternately in order to produce two different images with complementary information. One of the A/D channels is the standard one, which reads either the Z piezo signal or the error signal (log(I) for STM or A-B for SFM). The other A/D channel reads the signal from the LOCK-IN IN input on the back of the STM or SFM Control Module. A typical way to use this mode is to feed a small modulation signal (the modulation frequency that will be detected by a lock-in amplifier) into either Z MOD IN (for STM or SFM) or V MOD IN (for STM only) with an external function generator and read either I out or A-B out with a lock-in amplifier. The lock-in amplifier "locks-in" on the corresponding modulation signal induced by the inputted modulation signal. By plugging the output signal of the lock-in amplifier into LOCK-IN IN you can simultaneously record the topography (Z data) and the local conductance (dI/dV). An external AC modulation source and lock-in amplifier are necessary.

Mode 6 (CITS): In this mode images are 64 by 64 data points, and spectra are taken at each point. Only 16 spectra will be displayed at one time, but any can be viewed. Also, several spectra can be averaged to enhance signal-to-noise.

Withdraw Tip: When you select this function, the piezo will fully withdraw so that the sample is pulled away from the tip. You can also withdraw the sample using the SLOW FEEDBACK switch on the STM or SFM Control Module.

10.1.2 X-Scan Rate

This function lets you set the X0 scanning frequency, in lines per second (Hz). It is usually best to scan more slowly, as feedback tracks better. To save time, the X0 scan rate can be increased. The maximum scan rate depends on several factors, such as scan size, surface topography and conductivity.

If you are using STM, you want to protect the tip by not scanning too fast. For STM scans larger than about 0.1 μ, the scan rate should not be any higher than about 10 Hz. (Remember also to adjust FAST FEEDBACK parameters so that feedback can track the surface well and the tip will not touch the sample.) For scans as small as 50 Å you can scan at 60 Hz without damaging the tip, as long as the surface is atomically flat.

SFM tips are not as delicate as STM tips, but for scans 25 μ or larger the scan rate probably should not exceed 4 Hz. Use the scan rate in conjunction with feedback gain and time constant to achieve optimal feedback conditions.

For both STM and SFM the feedback tracks better at slower speeds. For very small scans of flat surfaces, a fast scan speed may be appropriate. Scanning fast will help to eliminate low frequency noise, which can obscure features in the smallest-scale images. For example, if you scan at 45 Hz and maintain a minimal feedback gain (about .2), feedback will track low frequency components like sample slope, thermal drift, and low frequency vibration. But it will not track atomic features, whose data rate is about 1 KHz, so these

appear in the error signal. Thus the data have effectively been high-pass filtered. If using constant-height mode, you essentially want to disable feedback, so the scan rate should be high.

Note that in Mode 6 the maximum possible scan speed is 1.2 Hz because spectra are being taken at each point.

Remember to readjust FAST FEEDBACK parameters (GAIN and TIME CONSTANT) after changing the scan rate, as they are scan-rate dependent.

10.1.3 Spectrum Rate

This function lets you set the rate at which spectra are taken, in Hz, and the number of spectra to be averaged at a given point; this option will be available only if you are using Mode 1. The appropriate values depend on the stability of the tip, background vibration level, and sample conditions.

10.1.4 Feedback Period

This option appears in place of Spectrum Rate when using Mode 6. In Mode 6, at each data point, the feedback is turned off while the voltage is ramped. At the end of the ramp the voltage is switched back to its initial value. There is a delay before feedback is re-activated so that the tunneling current can settle to its normal value. The duration of the delay is set by this option. The default is 20 clock cycles. Because the X position is moved after 20 clock cycles, the feedback period should not be much longer than this, or the tip may hit the sample when it moves in the X direction.

10.1.5 Take Data

When you select this option, the program will move to the Take Data menu, which is described below in Section 10.5.

10.1.6 Time Date

This option lets you set the time and date on the computer. The time and date when an image is taken are saved with the file. This needs to be set only when power to the CPU is interrupted.

10.1.7 Extended Configuration

This option lets you change the system configuration parameters. These are stored with each file and saved at the end of a session. When you begin a new session, they will be called up so that you do not have to reset them all each time.

Some of these parameters, including the Z piezo sensitivity, X and Y piezo sensitivities, and data storage device, can only be changed here and should be set before taking data or saving images. (Set the piezo sensitivities when you re-calibrate a scanner or change scanners.)

Others, including the X scan rate, spectroscopy scan rate, number of spectroscopy scans per point, source of spectroscopy, bias-voltage polarity, and SPM Mode, are more easily

set by using other options in the Set Up menu described above. The power of the automatic tilt correction and display Z scale are best set in the Display Options menu, Section 10.2.

The remaining parameters generally need never be changed.

When you select the Extended Configuration option, the system configuration parameters will be displayed on the right hand side of the screen. Use the cursor keys to move up and down in this list, and press <Return> to change the parameter currently selected. Type in the new value of the parameter and press <Return>. To return to the Set up menu, select Exit. The parameters are:

Z-Piezo Sensitivity: This is the Z piezo sensitivity in Å/V and must be calibrated. If using a 10 μ scanner, you can set the value to 80 initially. The calibration procedure is described in Appendix 5A.

X-Y Piezo Sensitivity: This is the sensitivity of the X and Y piezos in Å/V and must be calibrated. If using a 10 μ scanner, you can set the value to 240 initially; the calibration procedure is described in Appendix 5A. Only one value is used for the X and Y sensitivities. Actually, the Y0 axis will appear stretched due to piezo creep, so that distances along the Y0 axis will be larger than the equivalent X0 distances.

Stepper Motor Speed: This is the speed of the stepper motor that lowers the back of the STM or SFM head during computer-controlled operation. The default is 90 steps/second, and in ordinary use should not be changed. (This control is used with the UHV STM.)

Display Z Scale: This is the display amplitude for images and can be changed in the Display Options menu, as described below in Section 10.2.2.

Power of Automatic Tilt Correction: The first line of data can be fitted to an *nth*-order polynomial which is then subtracted from subsequent lines of data. If tilt power is 0, no subtraction is done. If tilt power is 1, a line is used. If tilt power is 3, a third-order polynomial is used. This can be set here, before taking data, or in the Display Options menu, as described below in Section 10.2.3.

X Scan Rate: This can be set here or as described in Section 10.1.1.

Spectroscopy Scan Rate: This parameter can be set here or as described in Section 10.1.3.

Number of Spectroscopy Scans/Point: This number can be set here or as described in Section 10.1.3.

Source of Spectroscopy (1 for I-V, 2 for dI/dV): Mode 1 lets you take I-V or dI/dV spectra at discrete points. Use this option to let the computer know which signal you are using.

Bias-Voltage Polarity: This is best changed when setting the scanning mode, as described above in Section 10.1.1.

Image Printer Address: This should be set to 9.

Image Printer Type: This should be Desk Jet/Laser Jet.

SPM Mode: This can be set here or as described above in Section 10.1.1.

Data Storage Device: This is the address of the data storage device. If you have an HPIB interface, then your floppy address will be :,700,1. The 40 M Byte hard disk drive is partitioned into three sections. The software is stored on :,700,0,0 which has 6 MByte. :,700,0,2 has 28 MByte and is the main data storage device. :,700,0,1 has 6 MByte and is for additional data storage. Select which device you want to use. If you want to save directly onto a floppy, this should be set to :,700,1. Check the data storage device before saving data.

Floppy Drive Address: If you have an HPIB interface, this should be set to :,700,1.

Last File Name Used: This will be set automatically when you exit the program, unless you stop the program with the <Stop> or <Reset> key.

10.2 Display Options Menu

LINEAR FACTOR	DISP AMP	TILT POWER *	CROSS HAIR	TAKE DATA		IV FULL RANGE	EXIT

This menu lets you do some initial data manipulation and image processing. The linear factor and tilt power should be set before taking images, since they actually change the data that are buffered. The display amplitude and I-V full range (for STM) let you optimize the display scale of the data but do not actually change the data. The Cross Hair lets you identify coordinates of points on spectra.

10.2.1 Linear Factor

This option lets you correct for piezo nonlinearity in the X0 direction as you take data. You can also use the Linear Correct function in the Image Processing program to correct for nonlinearity in either the X0 or Y0 directions.

The piezo nonlinearity is most obvious on large scans of periodic samples like the calibration grating. The lateral position of the tube is a nonlinear function of the voltage applied to the X and Y piezos.

The nonlinearity can be mapped to a good approximation with a third-order polynomial. The polynomial coefficients can be found using the Image Processing program; the correction can then be applied automatically as you take data (in the X direction only). Appendix 5A describes the procedure for finding the coefficients.

With the Linear Factor set to 1, the data will be corrected for nonlinearity in the X0 direction as they are collected. If you set it to 0, they will not be corrected.

10.2.2 Display Amplitude

Images should be displayed using the appropriate gray-scale range. This should be set for each image, but it can be optimized in the Set Up menu of the Image Processing program. If the display amplitude and offset are correctly chosen, the full gray scale will be used without saturating anywhere.

The display amplitude is the range in angstroms that corresponds to the full gray-scale range. If it is too small, the gray scale will be saturated, and parts of the image will be saturated black or white. If it is too small, the image contrast will be poor.

An offset can be added to the height of each data point, since the absolute height has no physical meaning. A positive offset will make the whole image lighter; a negative offset will make it darker.

10.2.3 Tilt Power

Sample tilt can usually be corrected with the SLOPE knobs on the SCAN CONTROL panel of the CCU. However, some tilt may remain in the data read by the computer, with the result that the image will appear dark on one side and light on the other. A first-order tilt correction can remove this.

With the Tilt Power set to 1, the first line of data is fitted to a line, and this line is subtracted from each subsequent line of data. In this way the sample tilt is removed.

Scans large enough to use most of the lateral extent of the piezo may show curvature in the Z direction, due to the geometry of the tube. As a result, the edges of the image may be lighter than the center. A third-order tilt (curvature) correction can remove this.

With the Tilt Power set to 3, the first line of data is fitted to a third-order polynomial which is subtracted from each subsequent line of data.

With the Tilt Power set to 0, the data are not changed, and the DC level of the data is in the image. It is almost always a good idea to have the tilt power be at least 1.

Be aware that more complicated tilts may be addressed by the Tilt Correction menu of the Image Processing program even when a tilt correction is used when taking data.

Note: Be aware that if a sample has features of similar size to that of the scan, the computer will convolve these effects when fitting the first line of data if you use a third-order correction. In this case it may be better to use a linear correction and subtract the non-linear tilt using the Image Processing program which allows more control.

10.2.4 Cross Hair

This function lets you identify coordinates of points on spectra using the mouse.

10.2.5 Take Data

When you select this you will enter the Take Data menu, described in Section 10.5 below.

10.2.6 IV Full Range

Once you have taken a Mode 1 image with spectra or a Mode 6 image, you can change the amplitude of the spectrum display (full-scale current).

10.3 Drift Compensation

This function is for use with the UHV STM only.

10.4 Buffer Data Menu

CLEAR BUFFER		A-TRACE IS *	GOTO Nth	PREVIOUS BUFFER	NEXT BUFFER	SAVE	EXIT

When you take an image, it is automatically stored in the buffer. Up to 48 Mode 1 images, 12 Mode 2 images, 3 Mode 3 images, 24 Mode 4 or 5 images, or 1 Mode 6 image can be stored in the buffer at one time. At the top right-hand side of the screen is a green bar that indicates how full the buffer is.

The Buffer Data menu lets you look at the images in the buffer and save them. Use Goto Nth, Previous Buffer, and Next Buffer to look at different buffered images. You can turn the amplitude trace (A-trace) off to make stepping through the buffer faster. Clear Buffer will erase the entire buffer.

You will be notified when the buffer is getting full; you will not be able to take an image if it would overflow the buffer. Instead, you will be taken to the Buffer Data menu so that you can save data you want and then clear the buffer.

If you save an image immediately after taking it, the image will not be buffered. However, if you save it from the buffer menu, it will remain in the buffer.

10.4.1 Clear Buffer

If you select this function, the buffer will be cleared, and unsaved images will be lost.

10.4.2 A-Trace

If you turn the amplitude trace (A-trace) off, it will take less time to step through the buffer.

10.4.3 Goto Nth

This function lets you call up any buffered image.

10.4.4 Previous Buffer

This function will call up the previous buffered image.

10.4.5 Next Buffer

This function will call up the subsequent buffered image.

10.4.6 Save

This function saves the buffered image that is currently called up. After bringing up a buffered image you can exit the buffer menu and go to the Save menu under Data Storage to change the heading on this particular buffer data. Then you can save from this part of the menu tree.

10.5 Take Data Menu

SET UP	DISPLAY OPTIONS	CONT. IMAGE	DISP WINDOW	TAKE IMAGE	TIME DATE	SAVE MENU	EXIT

This menu is used to take images. The Take Image and Continuous Image commands both take images. You can use the Display Window feature to see what region you have scanned and to close in on features of interest. You can use the Take Spectrum command to take a spectrum if you are using Mode 1. If you are using Mode 6, you can use the Manipulate Spectrum menu to select 16 spectra to view and manipulate.

Before taking an image, make sure that all of the electronics have been correctly set. In particular, the FAST FEEDBACK GAIN and TIME CONSTANT on the Control Module should be optimized. You should also have set the SPM mode as described in Section 10.1.1.

Images are displayed in two ways. On the left side of the screen there will be a gray-scale image--lighter areas are higher, darker areas lower. On the right side is an amplitude-trace image where profiles are plotted.

10.5.1 Set Up

This takes you to the Set Up menu described in Section 10.1 above.

10.5.2 Display Options

This takes you to the Display Options menu described in Section 10.2 above.

10.5.3 Continuous Image

When you select this option, images will be taken in succession until you select Stop Image; it will then stop at the end of the image. Only this last image is buffered. This is particularly useful for some atomic level scans where tip changes may occur between images. By taking a number of images in succession, the best image be acquired.

If you use this option with large scans, you will have to compensate electrically for slope in the Y0 direction as described in Section 5.3.1. Otherwise the DC level of the first few traces will have an offset.

10.5.4 Display Window

When you select this option, a white rectangle will show the current position of the scan compared to the full range of the scanner. An outer rectangle shows the maximum region that can be scanned. You can see whether the selected scan will run out of the range of the X and Y piezos. (The CLIPPING lights on the CCU are useful for this too.) You can use the knobs on the SCAN CONTROL panel of the CCU to change the scan region. Remember that if you change the SCAN SIZE MULTIPLIER or ROTATION you should reduce the SCAN SIZEs to zero first, and if you make large changes in DC OFFSET quickly you should withdraw the sample with STM.

If you select Close Up, the image you have already taken will be displayed in the middle of the screen with the current position of the scan superimposed on it. (The red border, if visible, represents the limits of the scan range). This is useful for changing the scan position for a close-up of a feature of interest.

10.5.5 Take Image

When you press this key, an image will be taken. This starts the Y scan and performs any tilt or linearity corrections on the first line of data.

10.5.6 Time Date

This function lets you change the time or date as in the Set Up menu, Section 10.1.5. (This option will not appear if you use Mode 1 or Mode 6.)

10.5.7 Take Spectrum

If you are using Mode 1, this option will appear instead of Time/Date. To use it, you must first take an image. If you choose this function, you can use the mouse to select a point on the Mode 1 image at which to take a spectrum; you can do this at up to eight points.

If you are using STM, the computer moves the tip to the designated spot, turns off the feedback, ramps the voltage (at a frequency designated by the user), and records the current. The voltage will be ramped from the bias voltage set on the Control Module to the same magnitude, with opposite polarity.

If you are using SFM, turn SLOW FEEDBACK to COMP before selecting a point so the computer can control the extension of the Z piezo. The range over which the Z piezo is extended is set when you set the mode to Mode 1 (see section 10.1.1 above). On the vertical axis A-B will be plotted in arbitrary units. A red line will show the value of A-0B used for feedback. You can calculate the operating force using: Force=kZ, where Z is the difference in extensions of the piezo (read off the horizontal axis of the plot) between the snapback point and the operating point, and k is the theoretical force constant.

The number of spectra averaged is set in the Set Up menu. These spectra will be saved with the image and can be manipulated in the Image Processing program. The vertical scale of the spectrum plot is set in the Display Options menu.

10.5.8 Manipulate Spectrum Menu

CLEAR WORK SP	SMOOTH WORK SP	dI/dV vs. V		TOGGLE CIRCLES	SELECT SPECTR	CHANGE SCALE	EXIT

If you are using Mode 6, this option will appear instead of Time/Date. When you take a Mode 6 image, only 16 out of 4096 spectra will be displayed at one time. Red circles on the image indicate which points correspond to the spectra displayed. (Selecting the Toggle Circles option removes these circles.) You can use the Manipulate Spectrum options menu to do some simple data manipulation. You can use the Select Spectrum option to look at the spectrum of a different point in the image. You can also use it to select a single spectrum to display in the center of the screen with scale indicators. If you then choose Smooth Work Spectrum, that spectrum will be fit to a polynomial. The dI/dV vs. V option calculates the derivative at each point. Clear Work Spectrum clears the spectrum in the screen center, and change scale sets the current range of the spectra.

A similar menu is available in the Image Processing program.

Clear Work Spectrum: When you select this function, the spectrum shown in the center of the screen will be cleared.

Smooth Work Spectrum: When you select this function, the spectrum shown at the center of the screen will be fitted to a polynomial of selected order.

dI/dV vs. V: This function is for STM only. When you select it, a spectrum shown at the center of the screen will be differentiated numerically and the derivative plotted as a function of V.

Toggle Circles: This function makes the red circles on the topographic image appear and disappear.

Select Spectrum: This function is used to select the points in the topographic image for which spectra are shown. To look at the spectrum at a particular point, use the mouse to move a red circle to that point. The spectrum at that point will be displayed on the right-hand side of the screen in place of the original spectrum. You can re-display a particular spectrum in the center of the screen by pushing the first and second mouse buttons when the cursor is over the corresponding red circle. If you do this again at a second point, the two spectra will be averaged. To fit the spectrum to a polynomial, use the Smooth Spectrum function; to clear the space in the center of the screen, use the Clear Work Space function. To differentiate the spectrum, use the dI/dV function.

Change Scale: This lets you change the current scale of the spectra.

10.5.9 Save Menu

This takes you to the Save menu, which will be discussed in Section 10.7.6 below.

10.6 Move Sample Menu

FORWARD	BKWRD	REMOTE CONTROL	AUTO APPRCH	MOVE Y AXIS	LEFT	RIGHT	EXIT

The Move Sample menu lets you lower or raise the microscope head to move the tip toward or away from the sample. To use this menu you must toggle the COMP/MAN switch on the SAMPLE APPROACH panel of the CCU to COMP.

Only the Auto Approach option is used frequently. It brings the tip close enough to the sample for feedback to operate, in a crashless manner. The Forward, Backward, and Remote Control functions let you move the stepper motor forward or backward, but this is more easily controlled with the FWD/BWD switch on the SAMPLE APPROACH panel by toggling the COMP/MAN switch to MAN. The other functions are for use with the UHV STM only.

The speed of the stepper motor when controlled by the computer is set in the extended configuration as described in Section 10.1.6. It should be 90 steps/second.

10.6.1 Forward

This option lets you move the tip toward the sample a chosen number of steps; one step is 300 Å.

10.6.2 Backward

This option lets you move the tip away from the sample a chosen number of steps; one step is 300 Å.

10.6.3 Remote Control

This option lets you control the stepper motor with the mouse.

10.6.4 Auto Approach

This option is used to lower the tip close enough to the sample for feedback to operate, as described in Chapters 5 and 7. For this function only, the SLOW FEEDBACK switch on the Control Module should be set to COMP so that the computer can control the position of the Z piezo. For STM you will be asked how many steps you want between piezo checks. The default, 10, should be used. The computer takes the designated number of steps and extends the sample forward with the piezo, checking for current. If none is sensed, it pulls back and repeats. When current is sensed, it will stop and pull the tip back. For SFM the computer extends the piezo to midrange and steps the motor continuously until a change in A-B is sensed, at which point it stops stepping and withdraws the sample. At this point turn the SLOW FEEDBACK to AUTO (and turn up the GAIN) to enable imaging.

10.6.5 Move Y Axis

This option is for UHV STM only.

10.6.6 Left

This option is for UHV STM only.

10.6.7 Right

This option is for UHV STM only.

10.7 Data Storage Menu

CAT SELECT		RE-NAME	PURGE DATA	LOAD DATA	BUFFER DATA	SAVE MENU	EXIT

The Data Storage menu lets you perform some file management operations. The most important option is the Save Menu, which lets you document and save files. The other options are duplicated in the Image Processing program and in the Shell Program, where they are more commonly used.

When you take an image, it is automatically saved in the buffer but will be lost when you exit the program unless you save it on a disk with the Save Menu. File names consist of R (for "raw data") followed by the year, month, day, and file number.

Before you use the Data Storage menu, check that the Data Storage address has been correctly set in the extended configuration, as described in Section 10.1.6.

10.7.1 Cat Select

This option lets you see what files are in the data storage device selected.

10.7.2 Re-Name

This option lets you save an existing file under a new name. (The original file will be purged.)

10.7.3 Purge Data

This option lets you delete a file from the active data storage device.

10.7.4 Load Data

This option lets you load a file from the active data storage device.

10.7.5 Buffer Data

This option will take you to the Buffer Data menu. (See Section 10.4.)

10.7.6 Save Menu

DATA NAME	SAMPLE NAME	X,Y SCALE	Vt, It	TOPO FROM	COMMENT	SAVE	EXIT

This menu lets you change the various elements in the file heading and then save the image. Of these elements, only the sample name, comment, and data name should be

changed. Data can also be saved from the Buffer Data menu, but there the file heading cannot be changed.

Data Name: It may be convenient to change the data name to make it easier to archive files. The data type should be a single letter, usually R for "raw data."

Sample Name: This option lets you set or change the sample name, which can be up to 50 characters.

X,Y Scale: If the X and Y piezo sensitivities used when taking data were incorrect, the X and Y scales displayed in the image heading will be incorrect. Calculate the scales using the correct piezo sensitivities and input them with this option. If the sensitivities are correct, the computer automatically reads the X,Y scale and stores it with the image.

Vt, It: If you are using STM, you can change the bias-voltage and tunneling current if necessary with this option. (You should never need to use it.)

Force: Force can be input after measurement from the F vs d curves.

Topo From: This option, which you should never have to use, lets you change the heading between Z and Log(I) (for STM) or A-B (for SFM). It also indicates the SPM mode used, where 1 is Mode 1, 2 is Mode 2, etc.

Comment: This option lets you add a comment of up to 50 characters in length to the image heading.

Save: When you select this option, the image currently being displayed will be saved onto the data storage device selected in the extended configuration, under the data name specified.

10.8 End Session

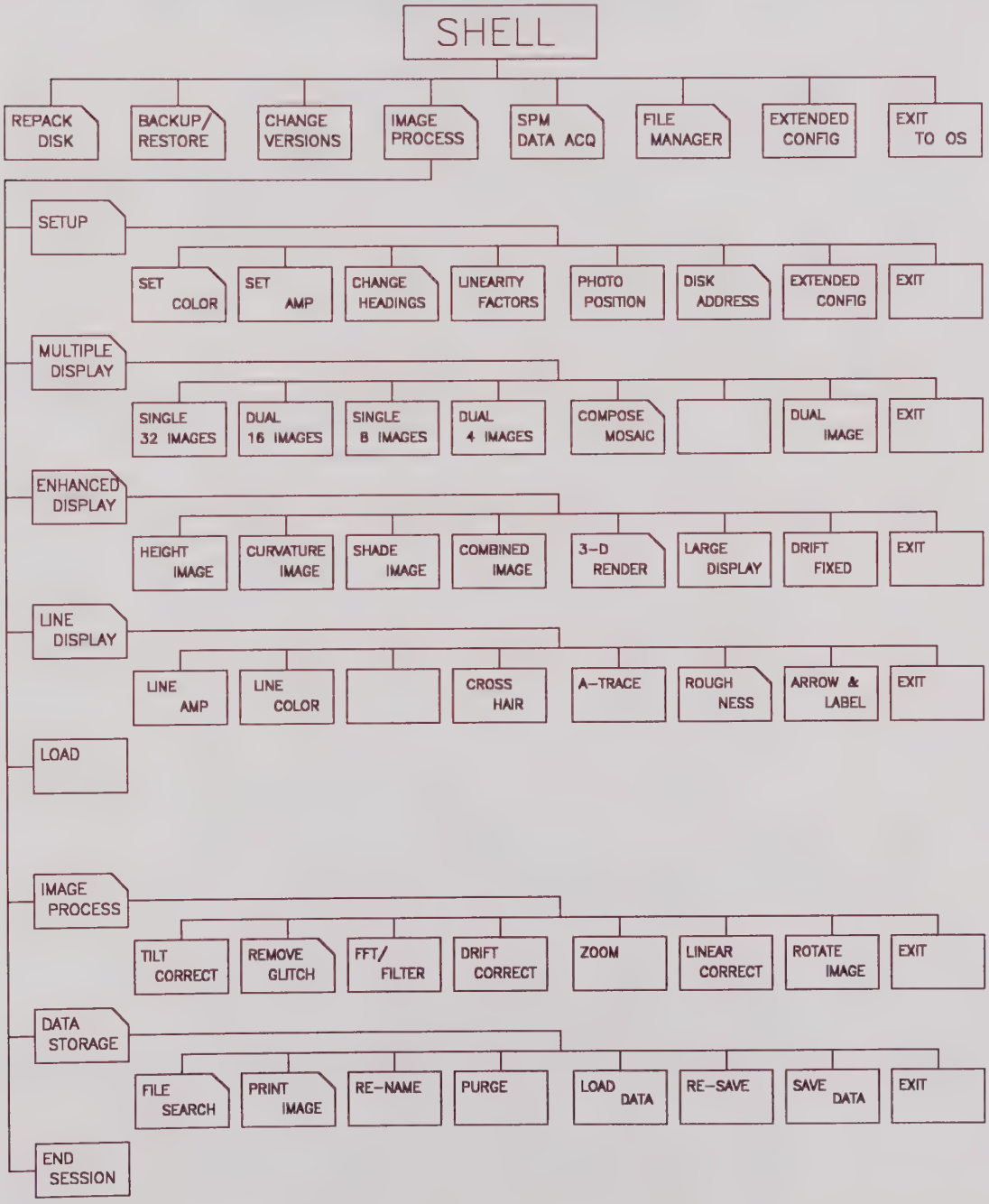
If you select End Session, you will exit the Data Acquisition program and return to the Shell Program. From there you can run the Image Processing program to enhance the images you have taken and extract quantitative information. You can also stop the Data Acquisition program by pushing <Stop> or <Shift>,<Reset>.

When you select End Session the system configuration parameters will be saved for use when you begin the next session.

To shut down, you can leave the program running but turn down the intensity of the screen. Switch the SLOW FEEDBACK switch on the Control Module to WDRW to withdraw the sample, and back up the head about 400 steps using the SAMPLE APPROACH panel on the CCU. Then shut off the power on the electronics.

11 Image Processing Program

The Image Processing program discussed in this chapter is used for processing images that were acquired using the Data Acquisition program. This package provides many functions to optimize images such as 3-D rendering, glitch removal, curvature and tilt corrections, surface roughness measurements and more.



This chapter describes all the functions associated with IP6_2, the latest version of the Image Processing program. The chapter format follows the structure of the menu tree above.

To run the Image Processing program, select it from the Shell Program menu. You can also load it from the BASIC operating system by typing `LOAD "IP6_2"`. (Consult the HP user manual on how to load and execute programs.)

In order to execute the actual functions of the menu, an image file must be loaded. We recommend that you go through the image processing tutorial (Chapter 6), which quickly shows how an image is affected by a particular image processing routine. This chapter concentrates on how the routine works.

11.1 Set Up Menu

SET COLOR	SET AMP	CHNG HDNGS	LINEAR FACTRS	PHOTO PSTN	DISK ADDRSS	EXTND CONFIG	EXIT

When Set Up is selected, a new sub-menu (shown above) is displayed.

11.1.1 Set Color Menu

BLUE	GOLD	CYAN	GRAY	CUSTOM DESIGN	INVERSE BK GND	HIDE MENU	EXIT

This option allows you to select a different color for the intensity map of an image with a single keystroke, design your own custom color table, save the current design color table, or load a previously saved color table. The new color setting will remain effective throughout the image processing session until you set a different color using the functions on this menu. Changing the color of the data display does not affect the quantitative information in an image. A "gray scale" is simply a way of depicting 3-D data on a 2-D screen. The intensity of a pixel corresponds to the relative height of the sample at that point, where bright is high and dark is low. The other color tables that are available simply assign different colors to different heights. Since the user can control the red, green and blue light tablets independently, an infinite number of color tables are possible; some will be more pleasing to the eye than others.

Blue: This function sets the system color table to blue.

Gold: This function sets the system color table to gold.

Cyan: This function sets the system color table to cyan.

Gray: This function sets the system color table to gray (gray scale).

Custom Design Menu:

				MODIFY COLORS	LOAD COLOR	SAVE COLOR	EXIT

The options under the Custom Design menu let you create your own color table for special purposes. These include enhancing an image by using different colors to highlight different topographic levels.

The **Modify Colors** option lets you change the color table. When Modify Colors is selected, a color bar will appear across the top right-hand corner, along with three rectangular windows. The color bar at the top of the screen is analogous to the vertical gray-scale bar next to any display image. The three windows correspond to red, green, and blue intensities as a function of height. These three colors can be added to produce other colors.

In each window the horizontal axis represents the percent of full Z axis range, and the vertical axis represents the intensity of that window's color. For example, to make the gray-scale color bar appear red on the left-hand side, draw a curve from the upper left-hand corner to the bottom right-hand corner of the red window using the mouse. To draw this curve, bring the cursor to the upper left-hand side of the window, click, and release the left button. Then bring the cursor to the lower right-hand corner, click, and release the left button. Hit the second button to finish. After you have drawn the curve, you will be asked if you need to smooth it. If you answer yes, a smooth curve will be drawn on top of the curve, and it will be used in defining the color table. The color bar at the top of the screen should appear red on the left-hand side. If you have an image on the screen, it will appear red at the lowest Z values. You can create different colors for different Z values by making different curves in the three-color windows. As mentioned earlier, there are many possible color tables, some of them pretty ugly, so some practice with this feature is worthwhile.

The **Save Color** command lets you save the color table to the active mass storage device. The **Load Color** command lets you load a color table which was previously saved using Save Color.

Inverse Background: This function toggles the background color of the display console between black and white.

Hide Menu: This function turns off the menu options on the bottom of the screen. Press any key to turn on the menu.

11.1.2 Set Amplitude

This function sets the amplitude of the gray-scale bar and the value of the Z offset added to the data. The expected input values are Maximum Z Amplitude and Offset. You can also set the gray scale using the standard deviation of the data amplitudes.

For many images it is desirable to set the amplitude and offset such that the data exactly span the gray scale. However, in others it is desirable to reduce the amplitude and change the offset so that the contrast is increased, although at some points the gray scale will be saturated. Also, if there are some glitches causing one or two points to have excessively large or small amplitudes, the image may appear too dark or too light. This problem can be avoided by normalizing the data using the standard deviation parameter and mean value.

To use the standard deviation feature to set the amplitude range, answer Y when asked: `CALCULATE STANDARD DEVIATION TO DETERMINE THE Z FULL SCALE AND OFFSET? (N)` Then the mean value of Z and the standard deviation of the data will be

calculated. The prompt `ENTER ST. DEV AND OFFSET. (2.5,0)` will appear. Enter the number of standard deviations you want the gray scale to span, and any offset from the mean value.

11.1.3 Change Headings

DATA NAME	SAMPLE NAME	X,Y SCALE	Vt, It	TOPO FROM	INSTRUM TYPE	COMMENT	EXIT

This set of menu keys allows you to change the heading of an image file. This is the name, parameters and comments inputted when the image was originally saved.

Data Name: This function allows you to change the current filename. The format of the new filename does not have to be the same as that used in the Data Acquisition program, but it must conform to the filename specification of the HP BASIC operating system. For example, the filename cannot be more than 10 characters long.

Sample Name: This allows you to change the name of the sample with a string of up to 50 characters.

X,Y Scale: This function allows you to change the X, Y scale parameters on the file heading.

Vt, It: This function allows you to change the tunneling voltage and tunneling current parameters on the file heading of STM images.

Force: This function allows you to change the force on the file heading of SFM images.

Topo From: This function allows you to change the topographic information on the file heading. If you are using STM, it can be either Z or log(I). If you are using SFM, it can be either Z or A-B.

Instrument Type: This function allows you to change the line in the file heading indicating the type of instrument that generated the image: UHV STM, AIR STM or AIR SFM. You will also be asked to enter the Z piezo sensitivity. Thus you can enter a new Z piezo sensitivity if desired.

Note: The above five parts of the heading were read by the computer when the image was scanned. Unless you are certain that one or more of these values is wrong, there should be no reason to change them. However, one common reason to change them is when the assumed piezo sensitivities in the system configuration were not correct for the piezo tube that took the image. To fix the image, multiply the number in the X,Y Scale stored with the image by the ratio of the right X,Y piezo sensitivities to the one assumed when the image was taken. For example, if the 10 μ scanner was assumed, but the 75 μ was actually used, the X,Y scale should be multiplied by 7.5. The Z scale can be fixed by simply changing the extended configuration file while the image is loaded and then re-saving the image.

Comment: This function allows you to change the comment line of the file heading. It can be up to 50 characters long.

Exit: When you press this key after using other functions in the Change Headings menu, you will be asked if you want to save all the changes you have just made under the original

file name. If you have changed the data name, you will not be able to re-save this image file under the new name, since the new filename may not exist on the disk. If the new filename already exists on the current data storage device, it will over-write the existing file. It is good practice to use the Save command under the Data Storage menu to save any image file with a filename that has been changed. This command checks for the existence of the new filename before writing it to the disk.

11.1.4 Linear Factors

This function performs non-linearity correction calculations to determine the third-order polynomial equation used in correcting the piezo non-linearities in the X and Y directions. The non-linearity is most obvious when you take an image that has periodically spaced features, such as the 2-dimensional gold grating. The spacings between gratings are actually equal, but may not appear equal in the images. You should determine the four linearity coefficient factors for every scanner tube that you use and re-calibrate the linearity when you re-calibrate the scanner.

To determine these coefficients for a particular piezo scanner, take a Mode 2 Z image of the diffraction grating using the full X-Y range of the scanner. Align the grating in the sample holder on the base so that the X-axis of the grating is parallel to the X-axis of the scanning direction. (The edge of the grating should be roughly parallel to the line between the two coarse-approach screws.) The linearity factor should be set to zero when you take the image. Set the feedback gain low and time constant high to smooth the image, and set the tilt power to 3.

After you have taken and saved an image using the grating, load it from the Image Processing program. To determine the linearity coefficients, select the Linear Factors function. You will be asked to draw a horizontal line across the image with the mouse. After you have selected a line, a window is displayed on the top right-hand corner showing a cross section of the data along the chosen line. This curve should be similar to a sinusoid. The red markers on the X-axis indicate the minimum of each valley of the curve. There should only be one red marker per valley. If there is more than one minimum per valley, this curve is not valid for determining the linearity coefficients. If this is the case, select another line; otherwise, accept it. The curve beneath the window shows the cumulative horizontal distances of the minima as a function of X. If there is no false minimum on the selected curve, this line should be a straight line. The red curve is the smooth fit of this straight line. The curve beneath these two lines is the plot of the correction polynomial equation. The linearity coefficients are calculated automatically and stored in the system configuration file. They are loaded whenever you run the Image Processing program or Data Acquisition program.

To examine the coefficients of the polynomial fit, select the Linear Factors function again. Then answer NO to the question asked. The current coefficients are displayed in parentheses, and you will be prompted to enter new values. Press <Return> to accept the current values, or enter a new set of coefficients if necessary.

11.1.5 Photo Position

This function displays the image in the center of the screen without menu keys and headings. It is mainly for setting up the image on the screen for a photograph.

11.1.6 Disk Address

This function allows you to select a different data storage device address. If the disk address that you require does not appear on the menu keys, select Other to enter the desired disk address.

11.1.7 Extended Config

This allows you to change the System Configuration parameters. Use the up/down cursor keys on the keyboard to move around the configuration file and press <Return> to select an item. Then type the desired change and press <Return>. When you select Exit, you will be asked if the extended configuration file should be saved (i.e. should these parameters be used when the Data Acquisition or Image Processing programs are next loaded).

11.2 Multiple Display

SINGLE 32 IMAGE	DUAL 16 IMAGE	SINGLE 8 IMAGES	DUAL 4 IMAGES	COMPOSE MOSAIC		DUAL IMAGE	EXIT

The Multiple Display function allows you to display multiple images on one screen page. When you exit it, you have the option to save all the image filenames appearing on the screen to disk under a new filename, as a list. The listed file will contain only the names of the files and not the actual data. You can print these images, but only one image will be printed per page on a LASER JET printer.

When you select one of the options, you will be asked `LOAD LISTED FILES OR INDIVIDUAL FILE (L/I) <L>.` If you want to load a previously saved multiple image, press <Return> for "listed files" and enter the filename. If you want to load images to generate a multiple image, type `I` and then type each filename to be displayed separately.

Multiple Display cannot show rendered images.

11.2.1 Single 32 Image

This function allows you to display up to 32 images of mode 1, 4, 5, or 6 data. For modes 4 and 5, you will be asked to select which of the two images you want to display.

11.2.2 Dual 16 Image

This function allows you to display up to 16 sets of data using mode 4 or mode 5, or combine modes on the screen. Remember that modes 4 and 5 are dual-image data. Both of these images are displayed.

11.2.3 Single 8 Images

This function allows you to display up to 8 images of mode 1, 2, 4, 5 or 6 data. For mode 4 and 5 data you will be asked to select which of the two images you want to display.

11.2.4 Dual 4 Images

This function allows you to display up to 4 sets of mode 4 or 5 data or combine modes on the screen. Remember that mode 4 and mode 5 are dual-image data. Both of these images are displayed.

Note: Mode 3 images cannot be displayed in these routines.

11.2.5 Compose Mosaic

This function is used for piecing several images together to form a single image. The function supports data in modes 1, 4, 5 and 6.

When the Compose Mosaic function is selected, you are presented with two choices, `INPUT NEW FILE` and `SAVE MOSAIC`. The `INPUT NEW FILE` lets you load files for use in constructing the mosaic image. `SAVE MOSAIC` is used to save the mosaic picture to disk. The image can be retrieved later using the Load Data function under the Data Storage menu.

To construct a mosaic picture, select Compose Mosaic. A new screen display appears with a window on the left-hand side. This window is the working area for the mosaic picture. Select the Input New File menu to enter the data filename. The image is loaded and displayed on the top right-hand corner of the screen. Use the mouse to select the starting point on the image by pressing the left mouse button once, then move the cursor to the mosaic window where you want the starting point to appear. Click the left mouse button once to place the image. If the image does not appear at the right location, answer no to the next question and enter the relative distance to shift the image in the X and Y directions. You can use as many images as you want using the Input New File command. After you have finished composing the mosaic picture, select Save Mosaic and enter a filename. You must begin the filename with the character "M" so that the file can be identified and correctly loaded as a mosaic image.

11.2.6 Dual Image

This function only supports Mode 4 and Mode 5 data files. It is used for overlaying dual-bias images taken simultaneously. The combined image will have two colors, one for each image, so that individual features for each image will not be lost in the combined image.

11.3 Enhanced Display

HEIGHT IMAGE	CURVTUR IMAGE	SHADE IMAGE	COMBIN IMAGE	3-D RENDER	LARGE DISPLAY	DRIFT FIXED	EXIT

The Enhanced Display menu is mainly used for generating 3-D rendered images. Before you can generate 3-D rendered images, you must select at least one of the following three functions: Height Image, Curvature Image and Shade Image. You can save the 3-D rendered image or get a hardcopy of this image if you have a Mitsubishi video printer.

11.3.1 Height Image

This function displays the gray-scale image at the top left corner of the screen. If the image is not a 256x256 data point image, it will be interpolated or reduced to 256x256 data points. If the data were taken in mode 4 or 5, you will be asked to select which of the two images to interpolate. For the interpolation, a 2-D cubic spline interpolation is used.

11.3.2 Curvature Image

This function displays the second derivative of the height. You will be asked to enter values of the standard deviation and offset. The standard deviation determines the gray-scale range of the image. The offset is simply a fixed gray-scale offset added to the image. Curvature enhancement is optional, but it is often useful to combine curvature images with height and shade images to enhance edges.

11.3.3 Shade Image

This function sets the gray level of each point in an image by simulating illumination by a light source whose position you can set. The direction of the light source is given by THETA and PHI. THETA is the angle between the light source direction and the Z-axis, and PHI is the angle between the X axis and the projection of the light source in the X-Y plane. Shade enhancement is often useful in bringing out details in 3-D rendered images.

11.3.4 Combined Image

This function combines height, curvature, and shade images into a single image. You must set the fractional contribution of each of these images. For example, to generate an image of 50% height image, 30% curvature image and 20% shade image, enter `0.5, 0.3, 0.2` and press <Return>.

To use this function, you must first generate at least two of the three possible height, curvature, and shade images. You do not need to generate a third image if you do not want it to contribute to the combined image. The sum of the contributions must always equal 1.

11.3.5 3-D Render

HEADING IS *	LOGO IS *	TOP VIEW IS *	H-FACTOR IS *	GENERAT RENDER	V-POINT IS *,*	R-SIZE	EXIT

The Height Image, Curvature Image, Shade Image and Combine Image functions are used primarily to prepare data for 3-D rendering. 3-D Render is the function that actually generates the 3-D rendered image.

Heading Is *: This function toggles the display headings of the rendered image on or off.

Logo Is *: This function toggles the PSI logo on or off on the 3-D rendered image.

Top View Is *: When Top View is on, a top view image will be displayed above the rendered image.

H-Factor Is *: This function lets you change the vertical magnification of the rendered image. Both the data and Z-axis are re-scaled so that no quantitative information is lost.

Generate Render: This option takes you to the 3-D Render routines. You can generate a rendered image by selecting Height Render, Curvature Render, Shade Render, or Combined Render; you must prepare height, curvature, shade, or combined image first.

HEIGHT RENDER	CURVTUR RENDER	SHADE RENDER	COMBIND RENDER	PRINT IMAGE	SAVE ON FILE	ARROW & LABEL	EXIT

Height Render, **Curvature Render**, **Shade Render**, and **Combined Render** generate 3-D rendered images using the appropriate rendered data. **Print Image** is used to generate a hardcopy of the rendered image at a local printer. This function is the same as the Print Image function in the Data Storage menu. **Save On File** allows you to save the rendered image to disk. Use a filename starting with "X," such as X91030212. **Arrow & Label** lets you label points on the rendered image.

V-Point Is *,*: This function shows the current setting of the 3-D rendered image view point. The first figure is the altitude angle, and the second figure is the azimuthal angle of viewpoint relative to the image surface. Both of these values can be changed by pressing this function key.

R-Size: This function shows the current setting of the 3-D render image display size. The default setting is 1 (100%). If you are using a Mitsubishi CP100 video printer, you need to reduce the render size to 70% so that the image will fit onto one page. To do so, press this function key and enter 0.7 at the input line.

11.3.6 Large Display

This function displays the current image into 512x512 pixel size.

11.3.7 Drift Fixed

This function is the same as the Large Display function above, except it is used for displaying an image that has been corrected for thermal drift using the Drift Correct function in the Image Process menu. In order to display the image correctly, the drift-corrected image must be saved before using this function.

11.4 Line Display

LINE AMP	LINE COLOR		CROSS HAIR	A-TRACE	ROUGH-NESS	ARROW & LABEL	EXIT

This menu lets you change the amplitude trace display that appears to the right of gray-scale images. The Roughness and Cross-Hair options let you generate quantitative data from your images.

11.4.1 Line Amplitude

This function changes the scale of the amplitude trace image.

11.4.2 Line Color

This function changes the color of the amplitude trace image.

11.4.3 Cross Hair

This function is mainly used for mode 4 and mode 5 data. It allows you to measure the X, Y and Z coordinates of points on the image. If the image is mode 4 or mode 5, the position of a point in one image will be correlated with a point in the second image when one cross-hair is drawn at the current cursor position and another is drawn at the corresponding point on the second image.

When Cross Hair is selected, a small cursor appears on the screen. When you move the cursor to the image region, you will see the X, Y and Z coordinates changing as you move the mouse.

11.4.4 A-Trace

This function displays the amplitude-trace image on the right side of the screen using the currently defined line amplitude and color.

11.4.5 Roughness

AREA STATS	LINE COLOR	BASELINE POWER	REFRESH	RESCALE Z	ZOOM X-SECT	SCREEN DUMP	EXIT

This menu invokes the roughness analysis routine. You can use this function to perform roughness calculations of cross sections or areas, or measure the distance between two points on an image. When you draw a line across the image, cross-section statistics are automatically calculated. To calculate area statistics, you must choose Area Statistics and select a region on the image. Line Color, Baseline Power, Rescale Z, and Zoom X-Section all are used with the cross-section display and associated calculations.

When you select the Roughness option, a new screen display appears, as shown in Fig. 11-2.

The roughness screen is divided into several windows. The coordinate table window is used to display the coordinate parameters when the mouse cursor is either in the image region or in the profile window. If the cursor is in the image region, the table shows the coordinate values (X, Y, Z) of the point indicated by the cursor. If you draw a line across the image with the mouse, its length is also displayed. You can draw up to eight lines; their lengths are numbered 1 to 8 respectively in this table.

Each time you draw a line across the image region, the height-profile window will display its cross-section profile. You can use the mouse to measure the distance between any two points on this curve, and the result will be displayed in the coordinate table window. To measure the distance between two points, first hold down the left mouse button and drag it to the second point. While you are holding down the first button, press the second mouse button to select this line. To undo this line, simply release the left button.

The Fourier transform (Power Spectrum) window displays the Fourier transform of the height-profile curve. It is useful when you need to know the frequency spectrum of the sample surface.

Beneath the Fourier transform window are the height-histogram and bearing-ratio windows, which refer to the cross section. The height-histogram window shows the distribution in height of the features of the cross section, and the bearing-ratio window plots the percentage of the profile curve above a given height.

The roughness window is divided into two columns, area and cross section. The first column displays area roughness statistics, and the second column displays cross-section roughness statistics. The RMS value is the standard deviation of the data from the best-fit line (for cross-section data) or best-fit plane (for area data). The average roughness is simply the arithmetic mean deviation. Peak-to-valley is the vertical distance between the highest and lowest data points.

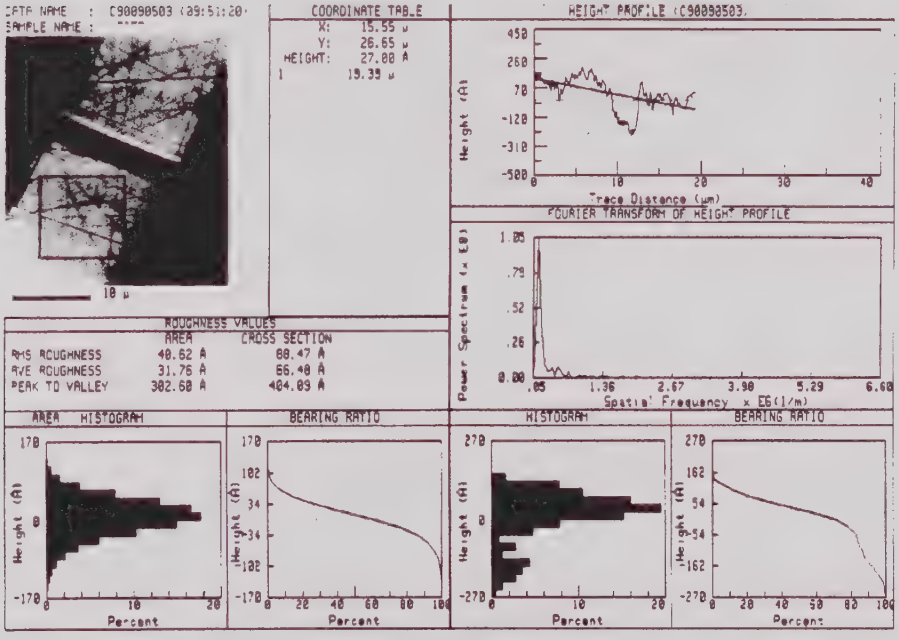


Fig. 11-2 Roughness Screen

Area Stats: This function performs roughness calculations on a selected region of the image. Press this key, then use the left mouse button to select the region of interest. The size of the selected region can be altered by moving the mouse while holding down the left button. When you have finalized the selection, press the second mouse button once. You will be asked whether you want to tilt correct this region of interest. If you do, it will find the best-fit plane for this region and use it to calculate the roughness data. Otherwise, it will simply assume this region has zero tilt.

Line Color: This function changes the pen color used in the plotting routines.

Baseline Power: This function allows you to change the order of the polynomial for fitting the baseline curve that appears in the height-profile (cross-section) window. Cross-section statistics are calculated relative to this line.

Refresh: This function clears all of the windows in the roughness screen.

Rescale Z: This function allows you to change the Z-axis scale in the height-profile window.

Zoom X-Section: This function allows you to display a portion of a cross section using the full range of the height-profile window.

Screen Dump: This function dumps the screen contents to a local printer. For a Mitsubishi CP100 video printer the screen is divided into two halves, one per page.

11.4.6 Arrow & Label

This function allows you to label your image with arrows and text. To label a point on the image, first move the cursor with the mouse to that point, then click the left mouse button and drag it to the place where the label will be. Click the left mouse button again. This defines the arrow. Pressing the right mouse button ends this function and allows you to enter text at the end of the arrow (pressing <Return> at this point will give an arrow with no label). The label will appear at the end of the arrow line after you press <Return>.

This function can also be used to title an image. Press the left mouse button where the title text is to appear, and then hit the right button (so no arrow is drawn). Now enter the title text and press <Return>.

11.5 Load

This function is used for loading an image data file from the current data storage device address. The default filename is that of the most recently used file increased by one. For example, if the current data file is R90120101, the default filename for the next input file is R90120102. If no file is currently loaded, the default filename will be that of the last file saved.

11.6 Image Process

TILT CORRECT	REMOVE GLITCH	FFT-FILTER	DRIFT CORRECT	ZOOM	LINEAR CORRECT	ROTATE IMAGE	EXIT

The Image Process menu options are used for correcting image-distortion problems like glitches, noise, tilt, thermal drift, and non-linearity. Many images can be improved using these routines, but we recommend using the least amount of image processing possible, as processing artifacts can be introduced by exessive filtering.

11.6.1 Tilt Correct

This function subtracts slowly-varying background signals, such as sample tilt, in either the X or Y direction. You can tilt-correct a selected area or the whole image. There are two methods of tilt correction in this image processing package, one correcting each line

independently and the other applying the same average correction to every line. Line-by-line tilt corrections in X and Y are performed differently, so it may be useful to rotate the image by 90° to use the correction that only the other axis has.

Tilt Correction Using Average-Height: This tilt correction applies the same correction to each line. If you tilt correct in the X direction, the computer averages all the X scans together to form the average X line for the image and displays this resutlt to the left of the image (this is displaying the average Z value as a function of X). It can be fit to a polynomial of a selected order, and this polynomial is then subtracted from each horizontal line of data. A tilt correction in Y is similar, but it finds the average Y line, and a best-fit polynomial is subtracted from each vertical column of data. In both cases you have the option of choosing a subset of the data for calculating the best-fit polynomial; the entire data set will then be corrected by this polynomial.

To select a subset of data for calculating the best-fit polynomial, answer no when asked `USE THE FULL RANGES IN BOTH X AND Y? <Y>`. Move the window to the region of interest. The size of the window can be adjusted by holding down the left button while moving the mouse; press the second button to accept the selection. The curve shown at the middle of the screen represents either the average height as a function of X or Y, depending on the axis of tilt correction. If you are performing a tilt correction along the X-axis, this line represents the average height as a function of X for the Y range data specified above (and vice-versa in the case of a Y tilt correction). The intensified region of the displayed average curve corresponds to the subset data and will be used to calculate the best-fit polynomial. The region outside the subset data will be linearly interpolated based on the slope of the endpoints of the subset data. In the case of a line-by-line correction the line curve displayed at the middle of the screen will be the first line of scan data where the subset data begins.

This kind of correction is used on images that have a fairly smooth background and large, localized features. Some practice is required to learn how to make optimal use of all the options.

Line-by-Line Tilt Correction in X: When you perform a line-by-line tilt correction of the data along the X-axis, every scan line in X will be fitted to a polynomial of specified order which is then subtracted from that line. This method is more time-consuming than the average-height method, but it is necessary in some situations. In particular, images whose curvature is in a direction different from X or Y will show curvature that is different for each X scan line.

You will be asked `SELECT BASE PLANE? <N>`. The base-plane selection is useful for correcting images within a specified height range. For example, the base-plane selection allows you to exclude large features in calculating the best-fit polynomial, as they will throw off the average if included. To exclude large features using the base-plane selection, press `Y` and `<Return>`. The computer calculates a height histogram and plots it on the right side of the screen. The left-hand side of the histogram curve corresponds to minimum height and the right-hand side corresponds to maximum height. The histogram lets you to select the height range of the data points which will be used in the correction calculation. Set the window on the histogram curve to include all but the large features (largest heights) in the example above.

You will be asked to enter the power of the polynomial fit. If you select a first-order polynomial, you need to enter the slope and bias values or use the default values. The slope and bias correspond to the slope and constant of the first-order linear equation.

Line-by-Line Tilt Correction in Y: If you tilt correct along the Y-axis, the average-height is found as a function of Y, and this average curve is subtracted from each vertical column of data. There is no polynomial fit. This function is useful when a horizontal row of data has an artificial DC offset, due to DC blocking or other low-frequency noise. (See the tutorial chapter for an example of data that uses this process.)

11.6.2 Remove Glitch

AVERAGE VERTICAL	AVERAGE HORIZON	AVERAGE LINE	OFFSET LINE			EXIT	ABORT

This menu allows you to remove glitches in images by replacing the Z value of selected points with the average of neighboring points. A region of 128-by-128 data points can be corrected at one time.

When you select this menu, three images will appear on the screen. The large image on the left is the working image. A smaller image at the top right corner is the original image, and that at the bottom right is the image with glitches removed.

Average Vertical: This function replaces the Z value of a selected point with the average of its vertical neighbors' Z values.

Average Horizon: This function replaces the Z value of a selected point with the average of its horizontal neighbors' Z values.

Average Line: This function replaces the Z value of every point on a selected horizontal line with the average of its vertical neighbors' Z values.

Note: Hitting the left mouse button in the above three menu options initiates the averaging routine; hitting the second button restores the original data.

Offset Line: This function removes a low-frequency or DC noise component from a horizontal scan line without removing higher frequency data. This noise may be due to DC blocking, for example. When you choose the Offset Line option, you will be asked to select two lines in the image. The first is a reference line which does not have the DC noise, and the second is the line you want to correct. Both lines will be fitted to polynomials, and the polynomial corresponding to the reference line will be subtracted from the polynomial corresponding to the noisy line. This difference is then subtracted from the noisy line.

Exit: This function exits the Remove Glitch routine and keeps the updated image.

Abort: This function exits the Remove Glitch routine and aborts all the changes you have made.

11.6.3 FFT/Filter

This function performs a 2-dimensional fast Fourier transform, Wiener and/or notch filter of the image data. The FFT algorithm transforms the raw data to the frequency domain where noise components of the data can be removed. Before performing the inverse fast Fourier transformation to the spatial domain, you can apply a notch filter or a Wiener filter (1/f noise filter) of selected strength, or remove specific Fourier components.

Note: The FFT/Filter function does not support Mode 3 data.

When the FFT/Filter function is selected, the computer clears the screen and displays the un-filtered image at the top right-hand corner. The bottom of the screen will read PLEASE WAIT...FOURIER TRANSFORMING. When the Fourier transformation calculation is finished, the screen shows the power spectral density at the center of the screen. The X-axis of the power spectral density corresponds to the data in the X-scan direction; the Y-axis corresponds to the data in the Y-scan direction.

The blank area under the heading FREQ DOMAIN BEFORE is used for displaying the power spectral density data in gray scale. To see the power spectral density data in gray scale, enter a non-zero numeric value when prompted to ENTER AMP FOR GRAYSCALE DISPLAY (0 FOR EXIT) <1>? The computer will keep asking this same question until a zero value is entered to continue with the program. Entering a small numeric value allows you to highlight certain data that was difficult to see when the display amplitude was too large. The reduced gray-scale image enables you to see the dominant signals of the un-filtered data. This is useful in determining which set of data to remove.

To remove certain data from the power spectral density curve, answer yes when asked REMOVE SPECIFIC COMPONENT? <N>; then press <Return>. The power spectral density display is replaced by the gray-scale display. To remove a specific set of data, use the mouse to place the small box over the region of interest. Adjust the size of the window by holding down the left button and dragging the mouse. Press the second button to accept the selected region. The computer will then generate a second window at the corresponding conjugate location. The question ANOTHER? <Y> is asking if you want to remove any more data. If you answer no, the next question appears: APPLY FILTER FUNCTION? <Y>. Answering yes allows you to apply the Wiener filter to the Fourier data. The Wiener filter is similar to a low-pass analog electrical filter circuit. The bandwidth of the Wiener filter is inversely proportional to the filter strength parameter. A small filter strength, such as 1, will have a larger bandwidth than a filter strength of 100. After you have selected a filter strength parameter, the computer will regenerate the power spectral density curve with the Wiener filter function applied. If the filter strength is large enough, you will see the attenuation of high-frequency components on the power spectral density curve.

If all the inputs are correct, press <Return> when asked ACCEPT? <Y>. Answering no will re-start the filter function without aborting it. If you accept, the computer will perform the inverse transformation and display the filtered image at the lower right-hand corner of the screen. If you want to keep the filtered image, press <Return> when asked ACCEPT? <Y>. If you answer no, the image will be restored to the original power spectral density, at which point you can start over. To exit this function, press the Abort key (f8) when it appears.

11.6.4 Drift Correct

Thermal drift may appear in atomic images. An image of a periodic atomic structure with thermal drift can be corrected using this function. There must be at least three axes of symmetry.

When you select the Drift Correct option, you will be asked, MEASURE THE ANGLES OF SYMMETRY AXES? <Y>. The angles between the axes of symmetry in the image will be different from their correct values, and you can measure these distorted angles.

(Ordinarily there is no way to know these distorted angles without measuring them, so you should answer yes.) To measure the angles, draw three lines, one along each axis of symmetry. The angles of these axes are displayed in degrees on the screen as A, B, and C. If you know the correct angles of symmetry from X-ray diffraction or LEED, you can use these angles to correct the image. In this case, answer yes when asked DO YOU KNOW CORRECT ANGLES OF TWO OF SYMMETRY AXIS? <N>.

Otherwise answer no. Then you will asked about the correct values of the angles between the axes of symmetry: ENTER THE ANGLE DIFFERENCES (A-B) AND (C-B). <60, 60>? You can type in different values for the angles or accept the default 60° if the crystal has three-fold symmetry, as is often the case.

The next prompt asks you to ENTER OTHER Yfactor, Slope OR PRESS <Return> TO ACCEPT. The current Yfactor and Slope will be displayed on the screen. If you think these values are not right, enter the new values, or press <Return> to continue. The Yfactor is defined as the ratio between the Y distance of the drift-corrected image and the Y distance of the uncorrected image. The slope is defined as the tangent of the slanted angle.

Now you will be asked, ARE THESE ADDITIONAL CORRECTIONS? <N>. If the image used for measuring the angles was not drift-corrected, press <Return> to accept the default. If the image has been corrected previously using this function, type Y and press <Return>. Each time you do a drift correction, the new information is recorded in the image data file. After you have answered the above question, the drift-corrected image will be displayed on the right side of the screen. If the image has a drift problem, and all the information was entered correctly, the drift corrected image should appear slanted.

You should re-save this image to disk if you want to keep these changes. The Drift Fixed menu under the Enhanced Display menu is used to display the corrected image in a larger size.

11.6.5 Zoom

This function allows you to trim an image. You can select a region of the image, and the data in that region are then interpolated to the size of the original data set. The image size will be smaller.

11.6.6 Linear Correct

This function applies a non-linearity correction to the images. If your image was not corrected for non-linearity during data acquisition, you can perform the correction here. Also, this function allows nonlinearity correction in both X and Y, whereas the correction during data acquisition (in real-time) is in the X direction only.

To apply the non-linearity correction to image, you must have previously measured the non-linearity of the piezo scanner in the Set Up menu. (The four coefficients COE0, COE1, COE2 and COE3 should all be set.)

When you press the Linear Correct key, you will be asked to ENTER DISTORTION FACTOR FOR X AND Y AXIS. (0..2, 0..2) <1,1> The distortion factor is a multiplier for the non-linearity correction polynomial. If you specify a zero factor value, there will be no correction applied. Use 1 to apply the correction if the image was

acquired under the same conditions as for the calibration grating image. If you applied a correction to the X axis during data acquisition, you should correct only the Y axis with this function, so enter `0,1`.

The corrected image will appear on the right side of the screen. Accept it if it has been properly corrected. Next you will be asked, `CORRECT PIN DISTORTION? <N>`. The linearity correction did not correct for Y dependence of the X nonlinearity or X dependence of the Y nonlinearity. These additional contributions to an image's nonlinearity can be removed by correcting the pin distortion. This is possible only with images that have parallel lines or structures that run roughly vertically.

Pin distortion correction will make the grating rows parallel (whereas nonlinearity correction made the spacing between rows constant). To perform a pin distortion correction you must "mark" two vertical rows using the mouse (these rows must pass through both the top and bottom lines of data). Put the mouse in the middle of the maxima of a grating row and click the left button. Repeat this at at least four different points on the same row, then press the right button to indicate that the first line has been marked. Repeat this procedure for a second line (it is best if these lines are as far apart as possible). The computer will then arrange the image to make the selected lines parallel.

11.6.7 Rotate Image

This function performs image rotation by 90°, 180° or 270° in a counter-clockwise direction.

11.7 Data Storage

FILE SEARCH	PRINT IMAGE	RE-NAME	PURGE	LOAD DATA	RE-SAVE	SAVE DATA	EXIT

Most of the functions in this menu are for performing basic file handling operations.

11.7.1 File Search

PREVIOUS DATA	NEXT DATA	JUMP	SELECT DATA	EXTRA OPTIONS	COPY TO FLOPPY	PURGE DATA	EXIT

When you select this menu, the computer will read all the filenames on the data storage device indicated in the extended configuration file. Before using the other menu options, you may want to use the Select Data option to choose the files you want.

Previous Data: This function loads and displays the data file previously displayed from the selected data files. If the current display file is the first selected file, no file will be loaded.

Next Data: This function loads and displays the data file next in the list of selected data files. If no data-file is currently displayed, it will load and display the first file from the selected files.

Jump: This function loads and displays the data file a selected number of files before or after the currently displayed file, from among the selected data files.

Select Data: This function allows you to select a set of consecutive data files. You can use "*" to substitute for any character. Thus if you type *910205* all files generated on February 5, 1991 will be selected, regardless of the initial letter.

Extra Options:

	FILE NAME	FILE HEADING	FILE IMAGES	LOAD DATA	COPY TO FLOPPY		EXIT

This menu provides extra options for file handling. **File Name** displays the names of the selected data files. **File Heading** displays the headings of the selected data files. **File Images** displays the selected images on the screen. **Load Data** loads and displays an image from the selected data files. **Copy To Floppy** copies some or all of the selected data files to floppy disk. The individual files option allows you to select a number of files among the select files with the mouse. It then copies these files to the floppy disk with a single key stroke.

Copy To Floppy: This function is different from the option of the same name under the Extra Options menu above. It copies the currently loaded file to the floppy disk.

Purge Data: This function deletes the currently displayed image from the data storage device.

11.7.2 Print Image

This function sends the current screen image to a local printer (i.e., Mitsubishi video printer or LaserJet printer). The image can be printed right away, or you can send the image to a batch file where print files can accumulate until you actually tell them to print by selecting the Batch File Print function. Using the batch file keeps the printer from occupying time that could be used for data acquisition or image processing. You should select the batch file print option when the computer is idle.

11.7.3 Re-Name

This function re-names a filename.

11.7.4 Purge

This function deletes a selected file from the data storage device.

11.7.5 Re-Save

This function saves the image currently displayed on the screen to the data storage device under its current filename, purging the older version.

11.7.6 Save Data

This function saves the image currently displayed on the screen to the data storage device under a new filename.

11.8 End Session

This function allows you to exit the Image Processing program to the Shell Program.

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Customer Support and Service

Park Scientific Instruments is dedicated to ensuring customer satisfaction and employs a team of scientists and engineers with extensive experience in the development and applications of scanning probe microscopes. PSI personnel are *always* available during normal business hours for consultation about new experiments and trouble-shooting; call 415-965-2976. In addition PSI can provide on-site training and field service support as required by the customer.

Before calling PSI with support or service requests, please be prepared with the following information:

CCU Model # _____

Module Model # STM _____ SFM _____

STM Head # _____

SFM Head # _____

Base # _____

Computer Model # _____

Software Revision #'s

Data Acquisition Program _____

Image Processing Program _____

Hardware Swap-Out Policy

PSI has designed the STM-SA1 and SFM-BD2 products for optimum reliability and convenience of operation. In the event of equipment failure PSI will supply replacement parts on loan, whenever possible, to enable field repair by customers with minimum downtime; once the system is operational, the defective parts are then returned to PSI. PSI stands behind each microscope system, as shown in our warranty statement at the beginning of this manual.

Software Support

PSI is grateful for all suggestions of suitable software enhancements and modifications and likewise appreciates reports of errors or bugs; call 415-965-2976.

PSI will provide software source code upon request to purchasers of complete microscope systems (including computer, microscope head and control electronics) under the following terms and conditions:

1. Source code is supplied for support of software customization by customers and is for use exclusively on the system for which it was supplied. Express written permission must be obtained if any PSI software, modified or unmodified, is to be used on instruments other than that with which the software was supplied.

2. PSI software source code is only supplied if the customer has executed a non-disclosure agreement protecting PSI's proprietary software product.

3. PSI will normally make reasonable efforts to assist customers in modifying software. However, PSI is not committed to provide support for customer-modified software of customer software development.

4. Customers are responsible for purchasing an appropriate compiler license as may be necessary for source code programming. PSI will supply details upon request.

In no event shall Park Scientific Instruments be liable to anyone for special, collateral, incidental, or consequential damages in connection with or arising from the use of PSI software, modified or unmodified.

Specifications

Ambient STM Head SA1-100

An ambient STM head to be used in conjunction with SA1/BD2-100 feedback module.

Open construction provides good visibility of tip-sample area. Compatible with 5mm travel X/Y coarse translation stage which comes as part of the STM/SFM scanner base assembly. Includes set-screw tip holder and high sensitivity pre-amplifier. Can accommodate flat samples up to 3 x 3cm. With a suitable sample holder the STM head can be used to image cleaved sample edges.

Complete STM systems are supplied with 120X monocular optical microscope, calibration gratings and sample holders. Low-profile design permits use of optional 1000x optical microscope SA-150 to monitor tip and select sample-imaging area.

Ambient SFM Head, BD2-100

Ambient SFM head to be used in conjunction with SA1/BD2-110 feedback module.

Unique open construction permits 90 degree arc visibility of Microlever-sample area for simplicity of alignment and precise sample positioning. Compatible with the 5mm travel X/Y coarse translation stage which comes as a part of the STM/SFM scanner base assembly.

Microlever deflection is detected by a diode laser and position-sensitive photo-detector. The head includes integral laser diode driver, photo-diode buffer amplifiers and sum and difference amplifiers.

Complete SFM systems are supplied with 100 Microlevers and toolkit, 120x monocular optical microscope, calibration grating and sample holders.

Ambient STM/SFM Scanner Base, SA1/BD2-110

Required for STM or SFM ambient microscope system. Features include:

Scanner base with automatic sample approach using stepper motor. Includes 5mm-travel X/Y coarse translation stage and acoustic cover. Stacked plate vibration isolation system.

Piezoelectric scanners are plugged into the scanner base and secured using four quick-release captive screws. Electrical contacts are automatically made by an integral connector, making scanner change a reliable and simple operation. Scanners are available with 125, 75, 35, 10 or 2.5 micron lateral motion (respectively 9, 7, 4.5, 2.2 and 1.1 microns vertical scan range). The standard scanner supplied may be either 2.5 or 10 microns as requested.

Table 1 - Standard 2.5 Micron Range Ambient SFM/STM Scanner Parameters

Scan Size Multiplier	Scan Range Å Max.	Offset Range μ	Z Range μ
1	250	2.5	1.1
10	2500	2.5	1.1
100	25000	2.5	1.1

Data Gain	Data Range (Resolution) Å
100	80(0.02)
10	800(0.2)
1	8000(2)

Table 2 - Standard 10 Micron Range Ambient SFM/STM Scanner Parameters

Scan Size Multiplier	Scan Range Å	Offset range μ	Z range μ
1	100	10	2.2
10	1000	10	2.2
100	10000	10	2.2

Data Gain	Data Range (Resolution) Å
100	160(0.04)
10	1600(0.4)
1	160000(4)

Scanning Microprobe Central Control Unit, SPC-400

Required for operation of any PSI microscope system. Works in conjunction with either STM Control Module or SFM Control Module. Features include:

Separate adjustment for scan size; three-decade scan size multiplier; coarse (x10) and fine (x1) X and Y position (DC-bias); X/Y-scan slope compensation; scan axis rotation; clipping indicators; bar-graph monitor for X, Y, and Z drive.

Provided with eight 700-V drive amplifiers for compatibility with either tube or tripod piezoelectric scanners. Five amplifiers are used for tube scanners (x+,x-,y+,y-,z) and the remaining three are for (x,y,z) tripod scanners.

Built-in X-Z mode oscilloscope for real-time monitoring of detector signal or data signal.

Manual or computer control of the Z approach stepper motor for sample positioning; digital step counter for easy repeat approach.

Computer interface board with control microprocessor, 96kByte of buffer memory, 80kByte of recirculating (downloadable) memory, four 12-bit DACs for X,Y & Z control and tunneling voltage, one 16-channel 12-bit A/D, and GPIB interface controller.

STM Control Module, SU2-210

Required for operation of UHV or ambient STM. Features include:

Temperature read-out with a relay for over-temperature bakeout protection of UHV STM head.

Tunneling parameters:
Current range: 10 pA to 10 nA.
Voltage range: 1 mV to 10 volts.

Dual analog feedback circuit--fast feedback to track atomic corrugations and slow feedback to compensate for slow thermal drifts in the Z-direction; variable gain and time constant for fast-feedback circuit; slow feedback can be turned on/off with track/hold switch or by computer; three-decade data gain to fully utilize the 12-bit A/D resolution.

SFM Beam Deflection Control Module, BD2-210

Required for operation of ambient SFM. Features include:

Beam deflection control module for diode laser and bi-cell detector; monitor for A+B, A-B and common-mode noise; common-mode noise-cancellation circuitry; supports manual and computer setting of force from $1X10^{-6}$ to $1X10^{-8}$ N in air; .5 Å cantilever deflection sensitivity; dual analog feedback circuit--fast feedback to track atomic corrugations and slow feedback to compensate for slow drifts in the Z-direction; variable gain and time constant for fast-feedback circuit; slow feedback can be turned on/off with track/hold switch; three-decade data gain to fully utilize the 12-bit A/D resolution.

HP Computer & Software, SU2-300

Required for operation of any microscope system. Features include:

HP 340C+ Workstation; 16.7 MHz 68030 with 68882 math co-processor; 4 MByte RAM; 16-inch color monitor, 1024 x 768 pixel with 64 gray levels; GPIB interface; Ethernet interface; Serial RS-232 interface; mouse; 40 MByte hard disk and 3-1/2 inch 2MB floppy-disk drive.

Optional upgrade to HP 345C+ Workstation (50 MHz 68030, 40 MHz 68882, 32kByte cache and 8 MByte RAM) available for increased image processing performance.

Full-featured software is provided for experiment control, data acquisition, and image processing.

Control software allows: automatic sample approach, real-time viewing of the scan data as well as capture and storage of multiple images without halting scanning. Captured images can be printed using a color graphic printer or laser printer. Supports imaging options of constant-current and constant-height modes. Supported spectroscopic modes are dual-bias voltage and localized I-V, dI/dV, dI/ds characterization. I-V measurement sites are user-selected from an image with the mouse and executed automatically.

Five modes of data acquisition are available:
Mode 1 - 128 x 128 data points per image
Mode 2 - 256 x 256 data points per image
Mode 3 - 512 x 512 data points per image

Mode 4 - two Mode 1 images taken at the same time at two bias voltages
Mode 5 - two Mode 1 images taken at the same time, one with height information, and the other with either dI/dV or dI/ds.
Mode 6 - 64 x 64 location I-V measurement, including measurement at user specified sites

Image processing software provides, inter alia: functions for multiple-image display (up to 32 images per screen), tilt correction, glitch removal, thermal drift correction, digital filtering via 2-D FFT (using Wiener optimal method), 2-D notch filtering, Fourier space image, contour mapping, mosaic composition, cross-section display, 3-D solid rendering using different rendering enhancements (height, curvature, shade, combined). A full-color translation table editor is provided including curve-fit smoothing to provide user-selected false-color coding. Custom color tables may be saved for later recall.

Surface roughness analysis software provides measurement of average, RMS and peak to valley roughness, as well as a power spectra and bearing ratio curves. Roughness analysis is computed along user-specified lines and areas of the image. Profile plotting software permits graphical display and measurement of step-height changes at user-specified sample regions.

PSI will provide source code (HP compiled BASIC) upon execution of a non-disclosure agreement. Source code is supplied for use solely on the PSI instrument sold with it. PSI does not commit to support of user-modified software. Source code modification requires purchase of an HP compiler license.

Optional Liquid Cell for Ambient STM/SFM Stage, BD2-120

Open liquid cell for aqueous operation of SFM with clear glass cover to ensure correct operation of deflection detector.

Optional Long Working Distance On-axis Optical Microscope, SA1-150

Option for either ambient STM or SFM system. Provides up to 1000X magnification for STM and 200X magnification for SFM. This provides a clear view of both tip (or Microlever) and sample and makes selection of imaging area quick and easy.

Features include:

10X long working distance objective is provided as standard for simultaneous use with either STM or SFM. 20X and 50X objectives are available separately for simultaneous use with STM only. Supplied with four position turret objective changer, 10X eyepieces and zoom optics providing 1X - 2X adjustment range. Includes Kohler illuminator with infra-red filter and aperture diaphragm, fibre-coupled halogen lamp and power supply. The microscope has integral coarse and fine focus and is mounted on a support pillar with total adjustment range of 12 cm, to accommodate either the PSI ambient SFM/STM or other samples. A 1" travel X/Y translation stage is provided for aligning the SFM/STM.

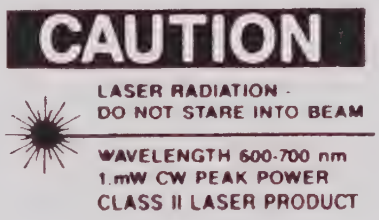
An optional black and white CCD camera is available complete with interface tube and mount, camera power supply, interface cables and a 9" diagonal black and white video monitor.

Image fields of view, with 2X zoom, are:

Objective	Eyepiece Field (Microns)	TV Field (Microns)
10X	1000 x 750	500 x 375
20X	500 x 375	250 x 187
50X	200 x 150	100 x 75

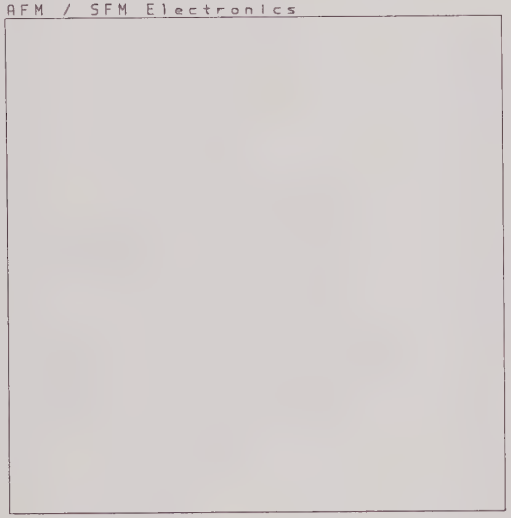
US DHHS Laser Warning

SFM BD2 contains a laser diode and displays the following warning label:



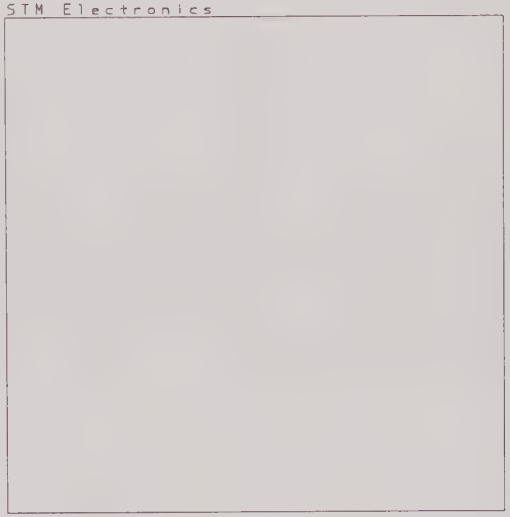
Prices and specifications are subject to change without notice.

AFM / SFM Electronics



SK01069.SCH

STM Electronics



SK01002.SCH

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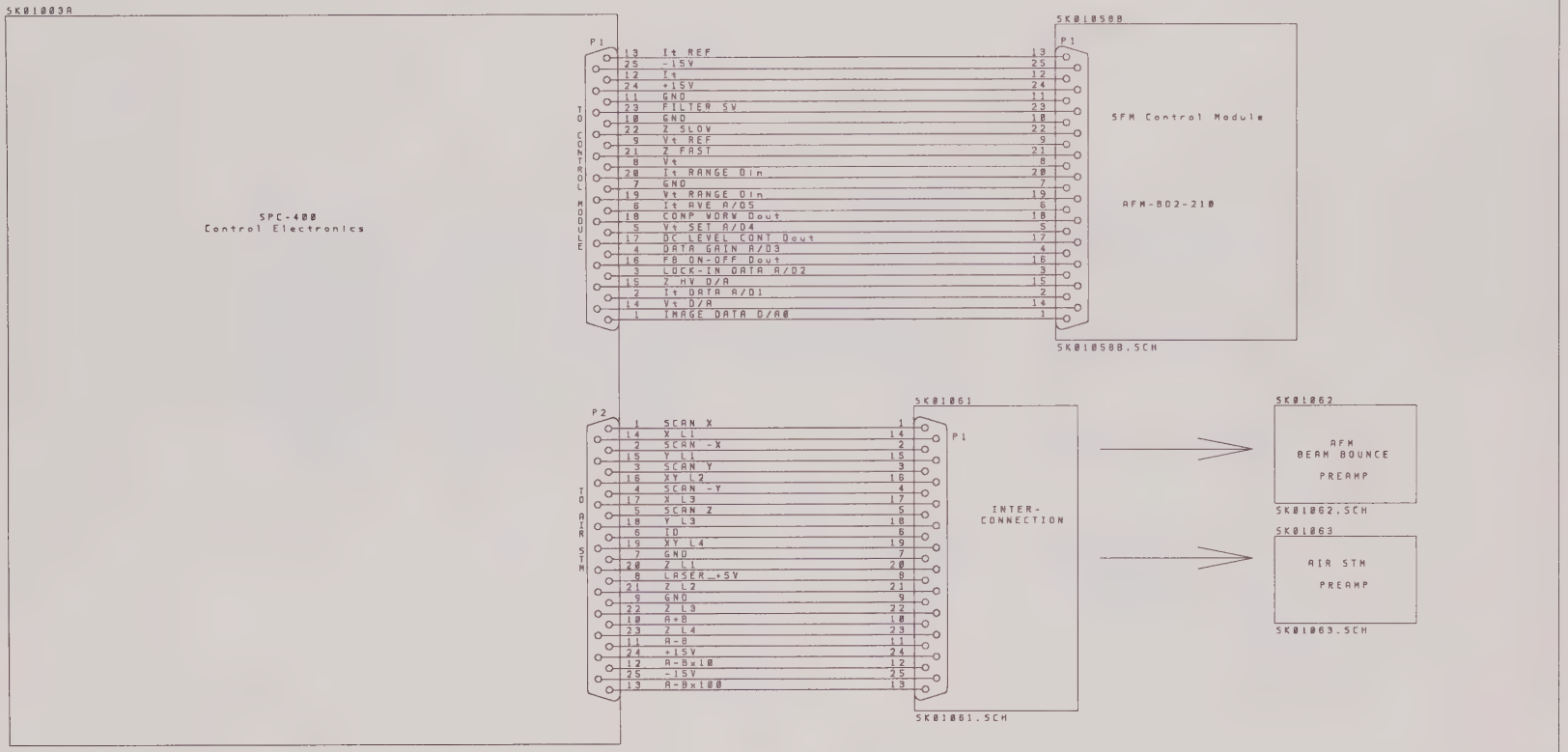
Title

Complete Schematic Set

Size	Document Number	REV
A	SK01070	-

Date: March 29, 1991 Sheet 1 of 1



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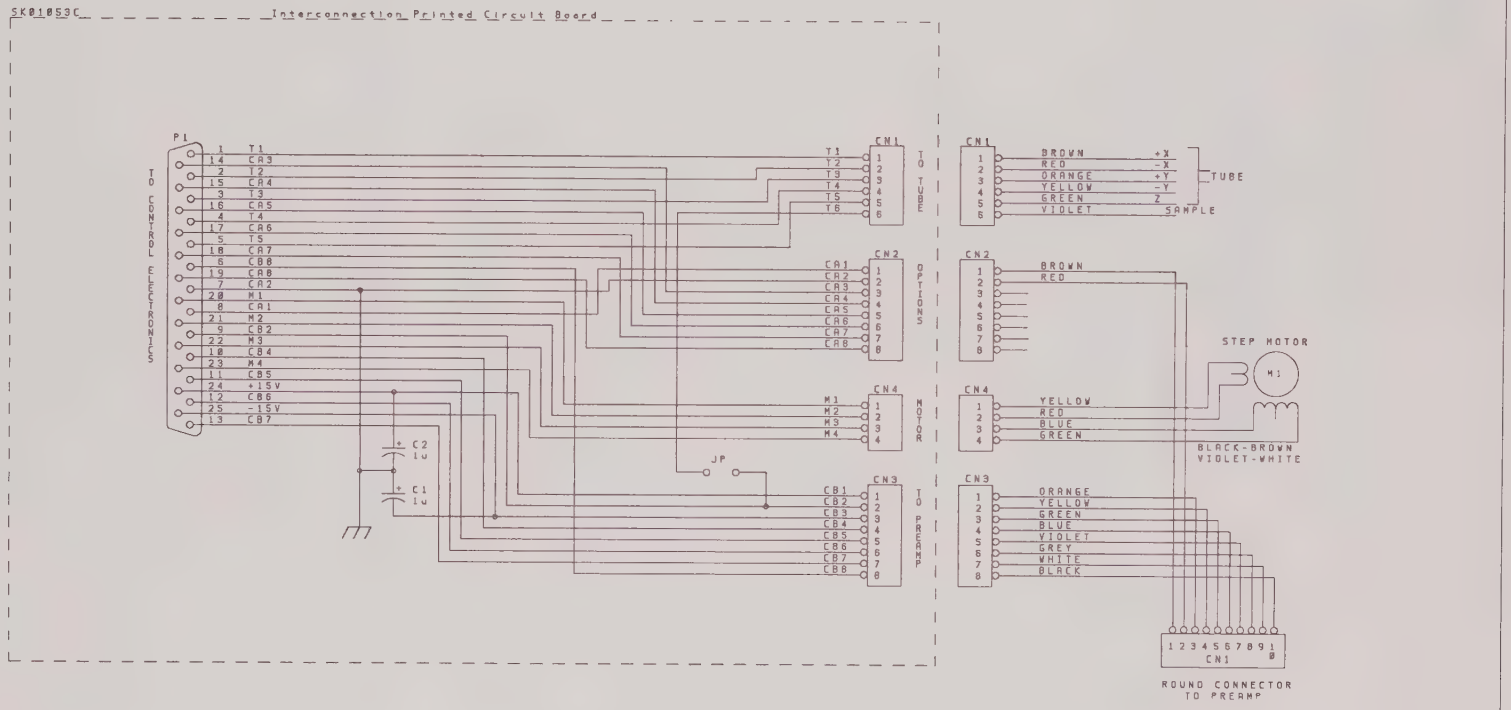
Title	Schematic, STM System	
Size B	Document Number SK01069	REV
Date: June 10, 1991	Sheet 1 of 1	



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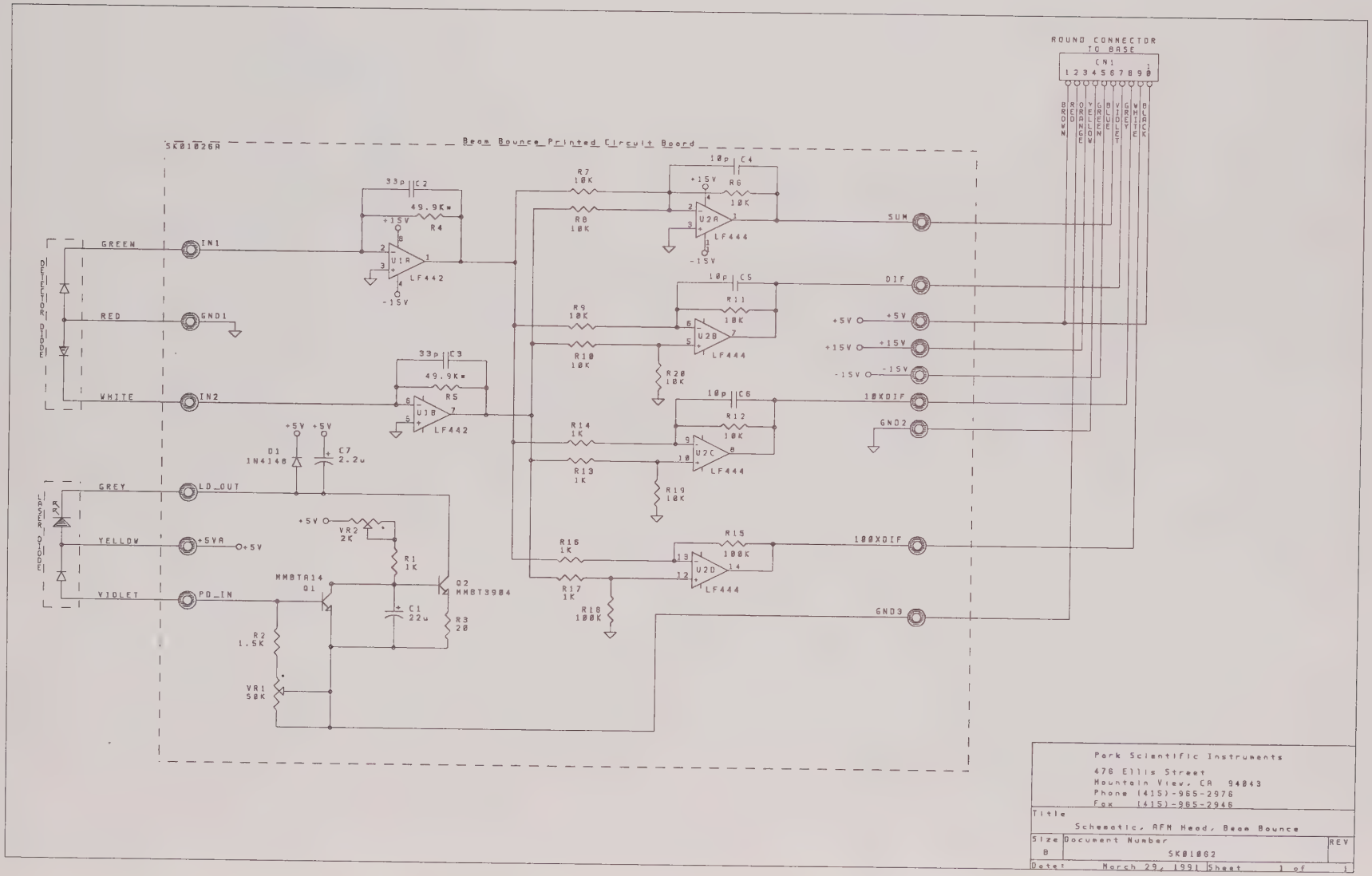
Title		
Schematic, AIR Interconnection		
Size	Document Number	REV
B	SK01061	
Date: June 27, 1991	Sheet 1 of 1	


ROUND CONNECTOR TO BASE
CN1
1 2 3 4 5 6 7 8 9 10
BROWN
RED
ORANGE
YELLOW
GREEN
BLUE
VIOLET
GREY
WHITE
BLACK
SK81026A
Beam Bounce Printed Circuit Board
DETECTOR DIODE
LASER DIODE
GREEN
RED
WHITE
GREY
YELLOW
VIOLET
IN1
GND1
IN2
LD_OUT
+5VA
PD_IN
+5V
-15V
33p C2
49.9K* R4
U1A LF442
33p C3
49.9K* R5
U1B LF442
D1 1N4148
C7 2.2u
VR2 2K
R1 1K
MMBTA14 Q1
Q2 MMBT3904
C1 22u
R3 20
R2 1.5K
VR1 50K
10p C4
R7 10K
R8 10K
R6 10K
U2A LF444
10p C5
R9 10K
R10 10K
R11 10K
U2B LF444
R20 10K
10p C6
R14 1K
R13 1K
R12 10K
U2C LF444
R19 10K
R16 1K
R17 1K
R15 100K
U2D LF444
R18 100K
SUM
DIF
100XDIF
GND2
GND3
Park Scientific Instruments
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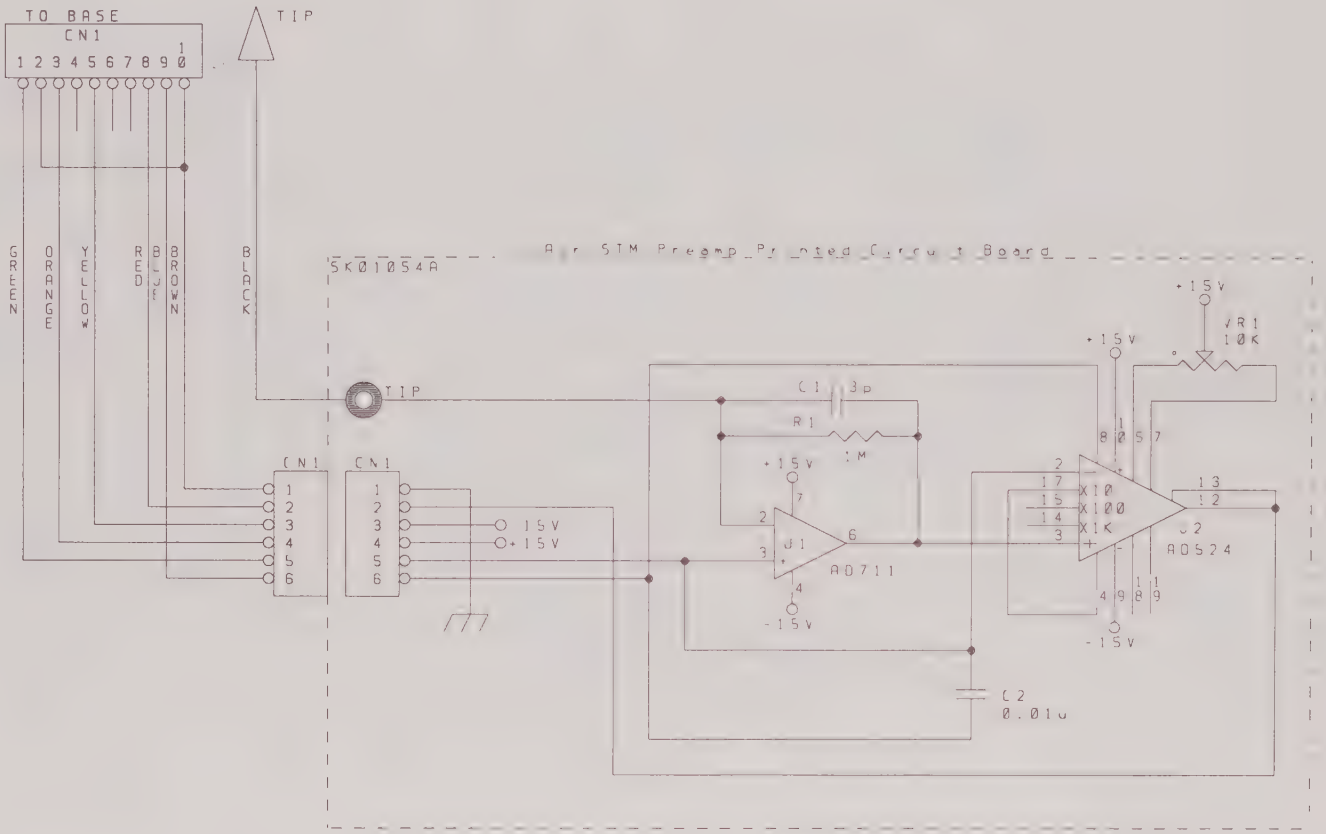
Mountain View, CA 94043
Phone (415)-965-2976
Fax (415)-965-2946
Title
Schematic, AFM Head, Beam Bounce
Size B
Document Number SK81062
REV
Date: March 29, 1991 Sheet 1 of 1



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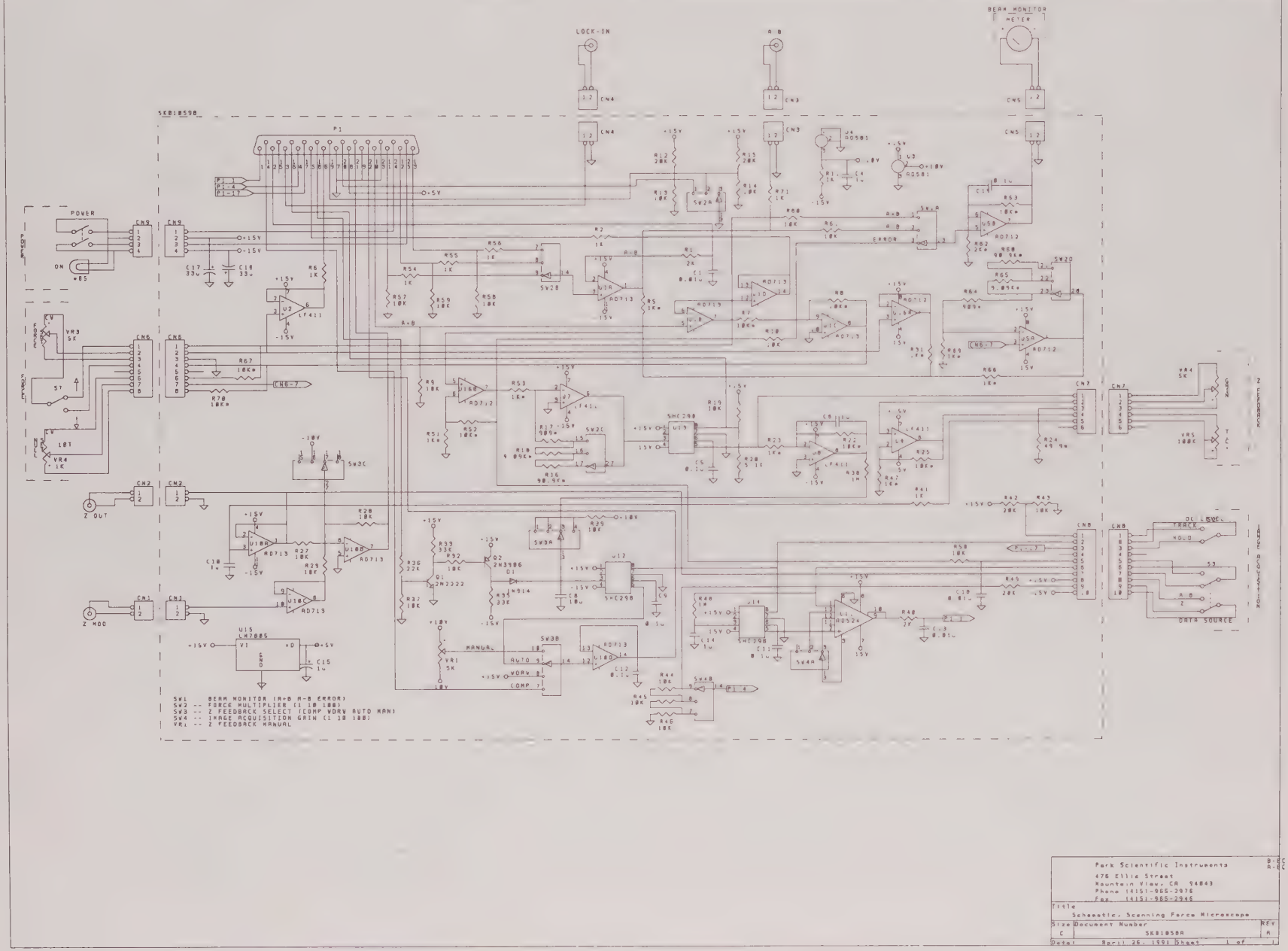
Title		
Schematic, Air STM		
Size	Document Number	REV
A	SK01063	
Date: March 29, 1991	Sheet 1 of 1	


LOCK-IN
A-B
BEAM MONITOR METER
SKB1858A
POWER
ON
Z OUT
Z MOD
MANUAL
AUTO
WORV
COMP
SW1 -- BEAM MONITOR (A+B A-B ERROR)
SW2 -- FORCE MULTIPLIER (1 10 100)
SW3 -- Z FEEDBACK SELECT (COMP WORV AUTO MAN)
SW4 -- IMAGE ACQUISITION GAIN (1 10 100)
VR1 -- Z FEEDBACK MANUAL
DC LEVEL
TRACK
HOLD
DATA SOURCE
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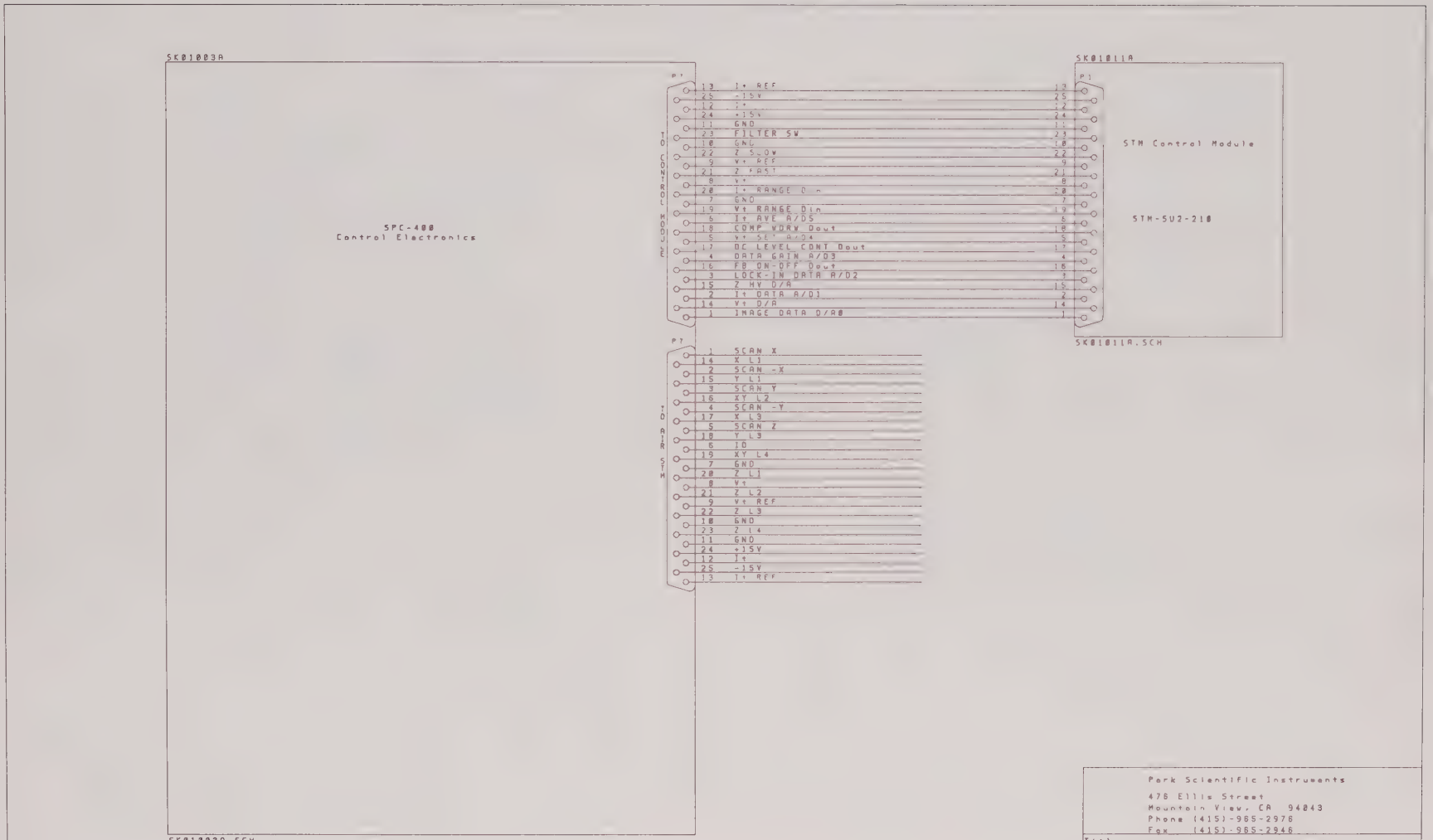
Title
Schematic, Scanning Force Microscope
Size
C
Document Number
SKB1858A
REV
A
Date: April 26, 1991 Sheet 1 of 1


SK01003A
SPC-400
Control Electronics
SK01003A.SCH
P7
TO CONTROL MODULE
13 I+ REF
25 -15V
12 I+
24 +15V
11 GND
23 FILTER SW
10 GND
22 Z SLOW
9 V+ REF
21 Z FAST
8 V+
20 I+ RANGE D-n
7 GND
19 V+ RANGE Din
6 I+ AVE A/D5
18 COMP WDRW Dout
5 V+ SET A/D4
17 DC LEVEL CONT Dout
4 DATA GAIN A/D3
16 FB ON-OFF Dout
3 LOCK-IN DATA A/D2
15 Z HV D/A
2 I+ DATA A/D1
14 V+ D/A
1 IMAGE DATA D/A0
P7
TO AIRSTM
1 SCAN X
14 X L1
2 SCAN -X
15 Y L1
3 SCAN Y
16 XY L2
4 SCAN -Y
17 X L3
5 SCAN Z
18 Y L3
6 ID
19 XY L4
7 GND
20 Z L1
8 V+
21 Z L2
9 V+ REF
22 Z L3
10 GND
23 Z L4
11 GND
24 +15V
12 I+
25 -15V
13 I+ REF
SK01011A
P1
STM Control Module
STM-SU2-210
SK01011A.SCH
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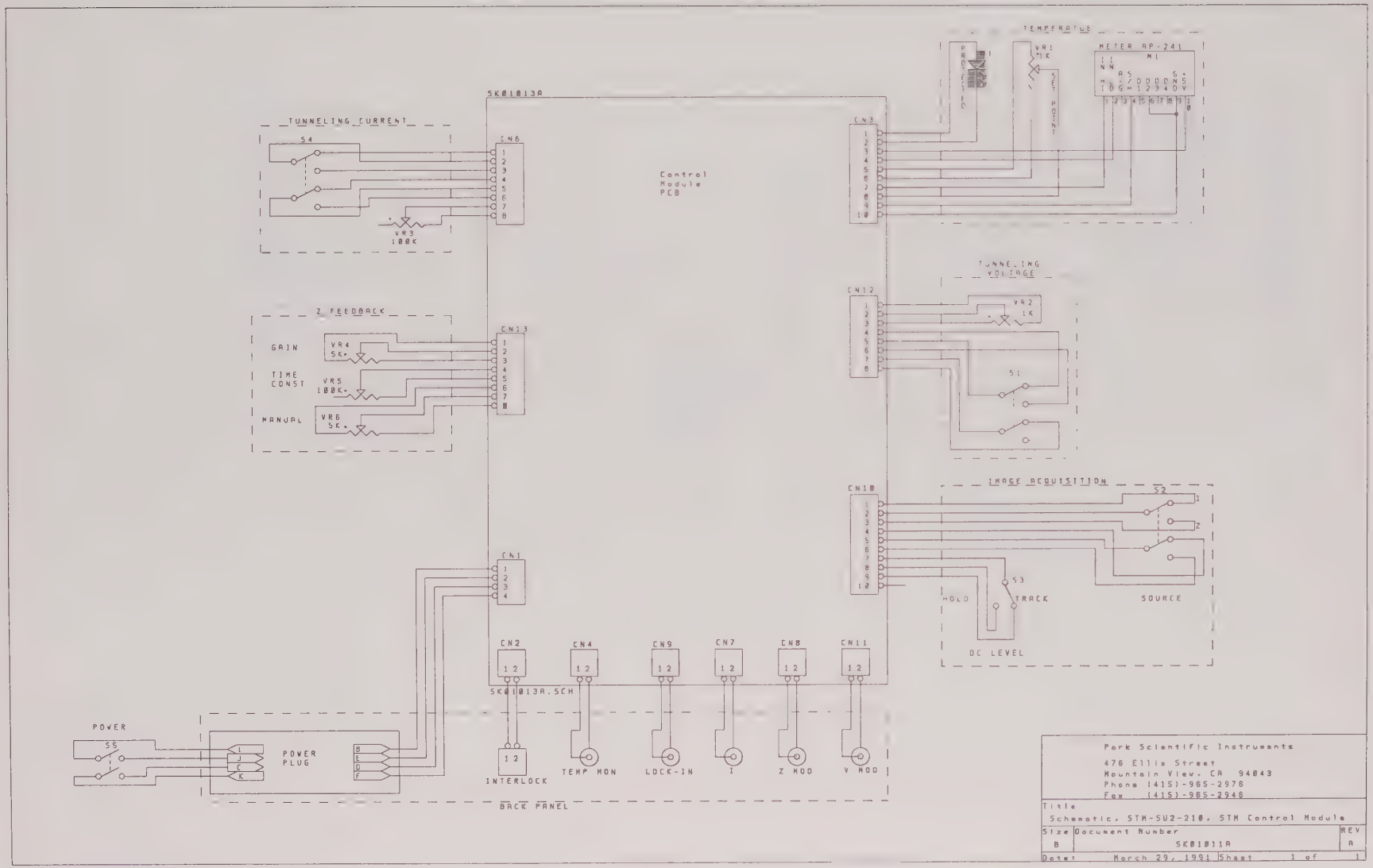
Fax (415)-965-2946
Title
Schematic, SFM System
Size 8
Document Number SK01002
REV
Date: June 25, 1991 Sheet 1 of 1


SK0101 3A
Control Module PCB
TUNNELING CURRENT
S4
VR3 100K
CN6
Z FEEDBACK
GAIN
VR4 5K
TIME CONST
VR5 100K
MANUAL
VR6 5K
CN13
TEMPERATURE
PROBE
VR1 1K
SET POINT
METER AP-241
CN3
TUNNELING VOLTAGE
VR2 1K
S1
CN12
IMAGE ACQUISITION
S2
S3
HOLD
TRACK
SOURCE
DC LEVEL
CN10
CN1
CN2
CN4
CN9
CN7
CN8
CN11
SK0101 3A.SCH
POWER
S5
POWER PLUG
INTERLOCK
TEMP MON
LOCK-IN
I
Z MOD
V MOD
BACK PANEL
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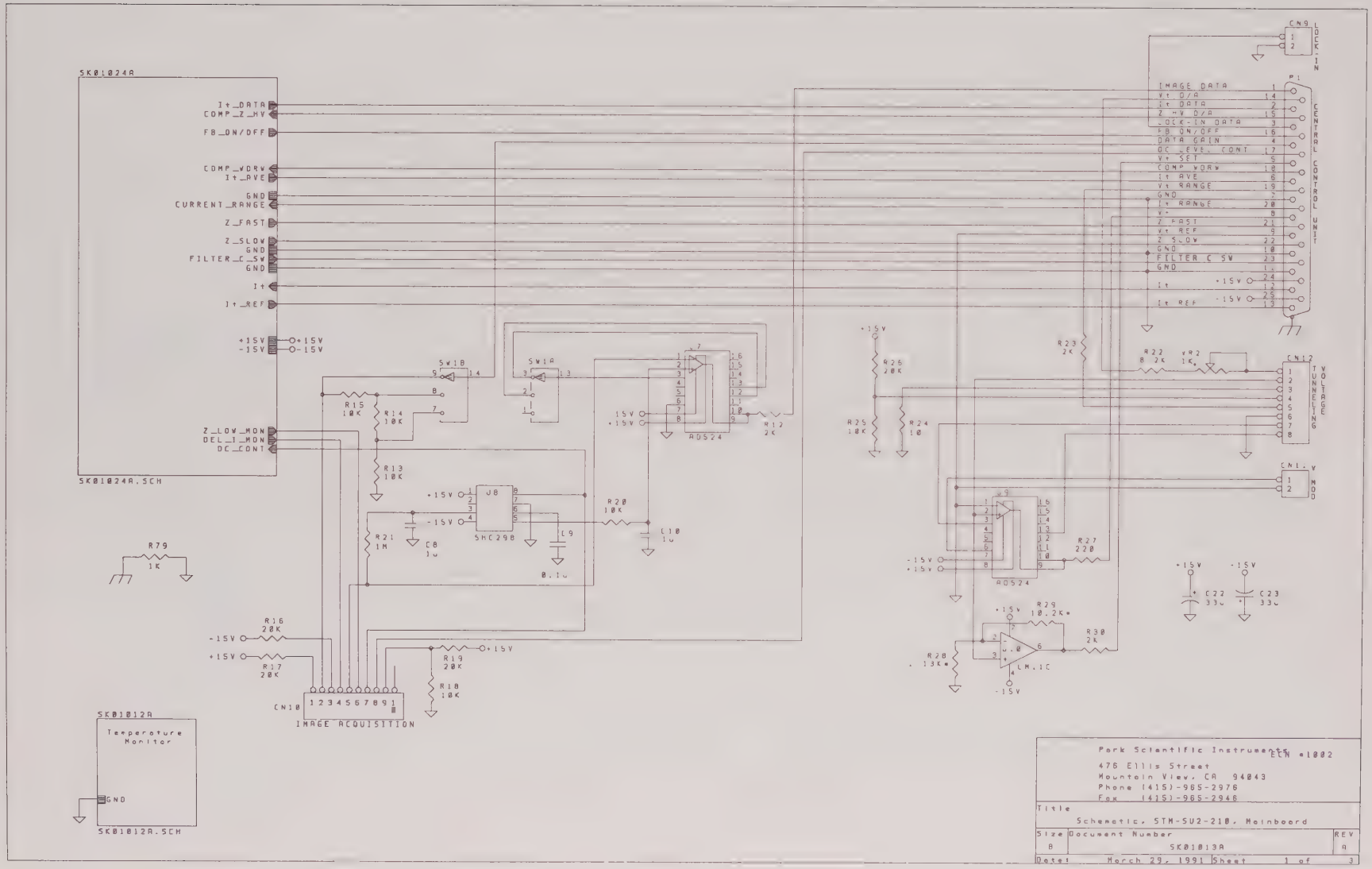
Fax (415)-965-2948
Title
Schematic, STM-SU2-210, STM Control Module
Size B
Document Number SK0101 1A
REV A
Date: March 29, 1991 Sheet 1 of 1


SK01024A
I+_DATA
COMP_Z_HV
FB_ON/OFF
COMP_VDRV
I+_AVE
GND
CURRENT_RANGE
Z_FAST
Z_SLOW
GND
FILTER_C_SW
GND
I+
I+_REF
+15V
-15V
Z_LOW_MON
DEL_I_MON
DC_CONT
SK01024A.SCH
SW1B
SW1A
R15 10K
R14 10K
R13 10K
R12 2K
AD524
+15V
-15V
U8
SHC298
R21 1M
C8 1u
C9 0.1u
R20 10K
C10 1u
R79 1K
R16 20K
R17 20K
R19 20K
R18 10K
CN10
1 2 3 4 5 6 7 8 9 10
IMAGE ACQUISITION
SK01012A
Temperature Monitor
GND
SK01012A.SCH
CN9
LOCK-IN
P1
IMAGE DATA
V+ D/A
I+ DATA
Z_HV D/A
LOCK-IN DATA
FB ON/OFF
DATA GAIN
DC_EVE. CONT
V+ SET
COMP VDRV
I+ AVE
V+ RANGE
GND
I+ RANGE
V-
Z FAST
V+ REF
Z SLOW
GND
FILTER C SW
GND
I+
I+ REF
+15V
-15V
CENTRAL CONTROL UNIT
R26 20K
R25 10K
R24 10
R23 2K
R22 2K
VR2 1K
CN12
TUNNELING VOLTAGE
CN1.V MOD
R27 220
R29 10.2K
R30 2K
R28 13K
LM.1C
C22 33u
C23 33u
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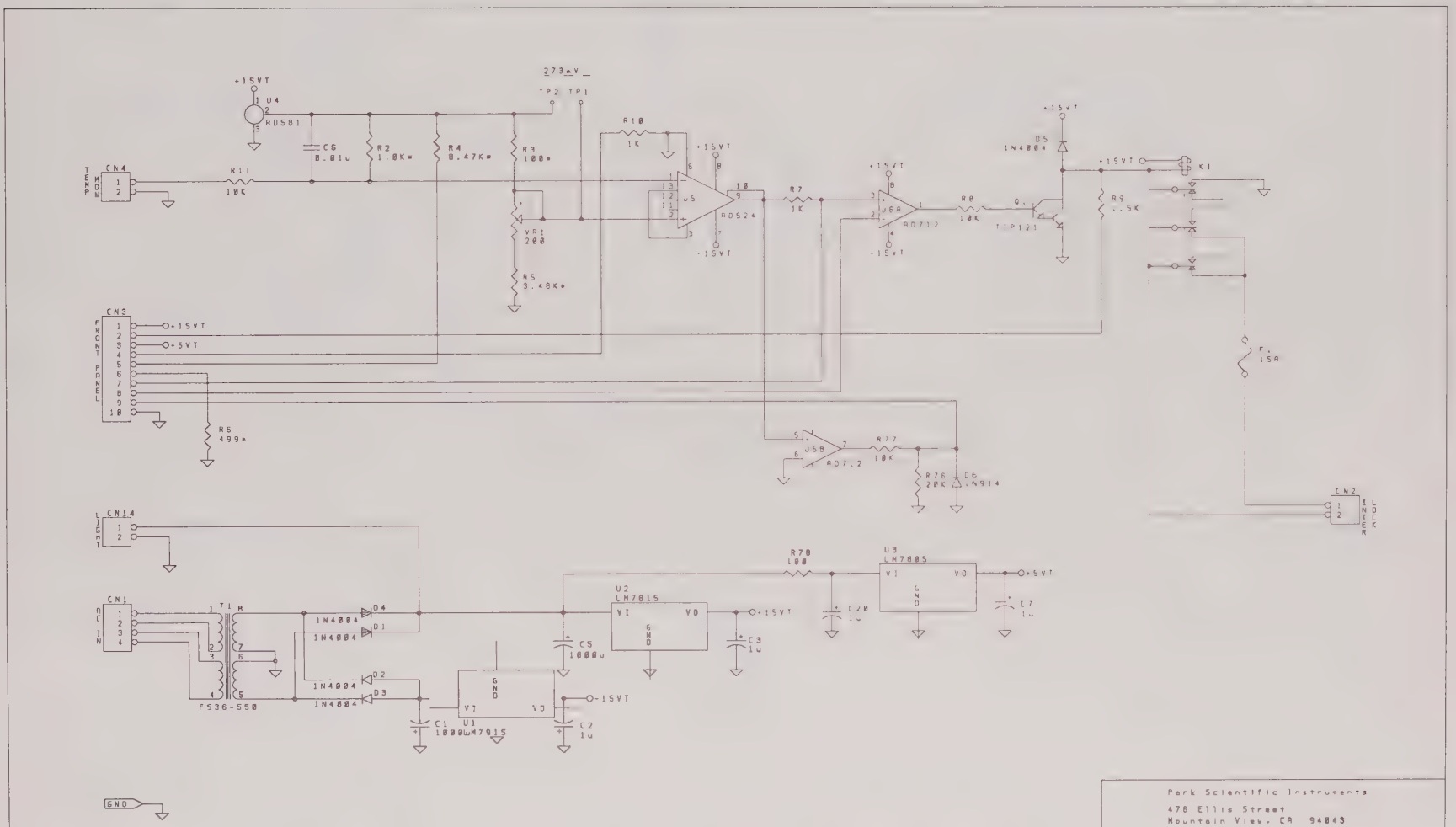
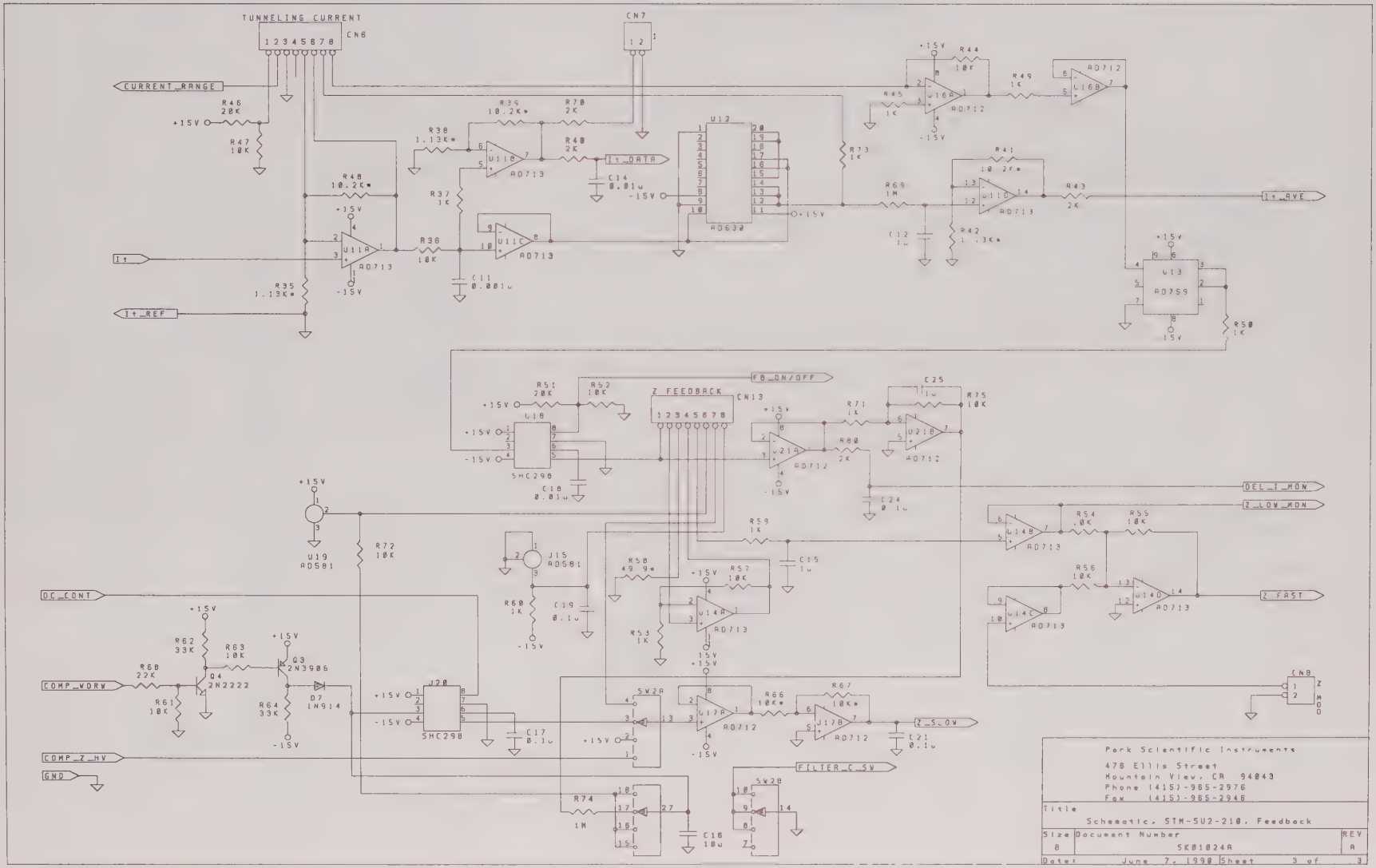
ECN e1002
Title
Schematic, STM-SU2-210, Mainboard
Size B
Document Number SK01013A
REV A
Date: March 29, 1991
Sheet 1 of 3



Park Scientific Instruments 478 Ellis Street Mountain View, CA 94043 Phone (415)-965-2976 Fax (415)-965-2946		
Title: Schematic, Temperature Monitor		
Size: B	Document Number: SK01012A	REV: A
Date: March 29, 1991	Sheet 3 of 3	



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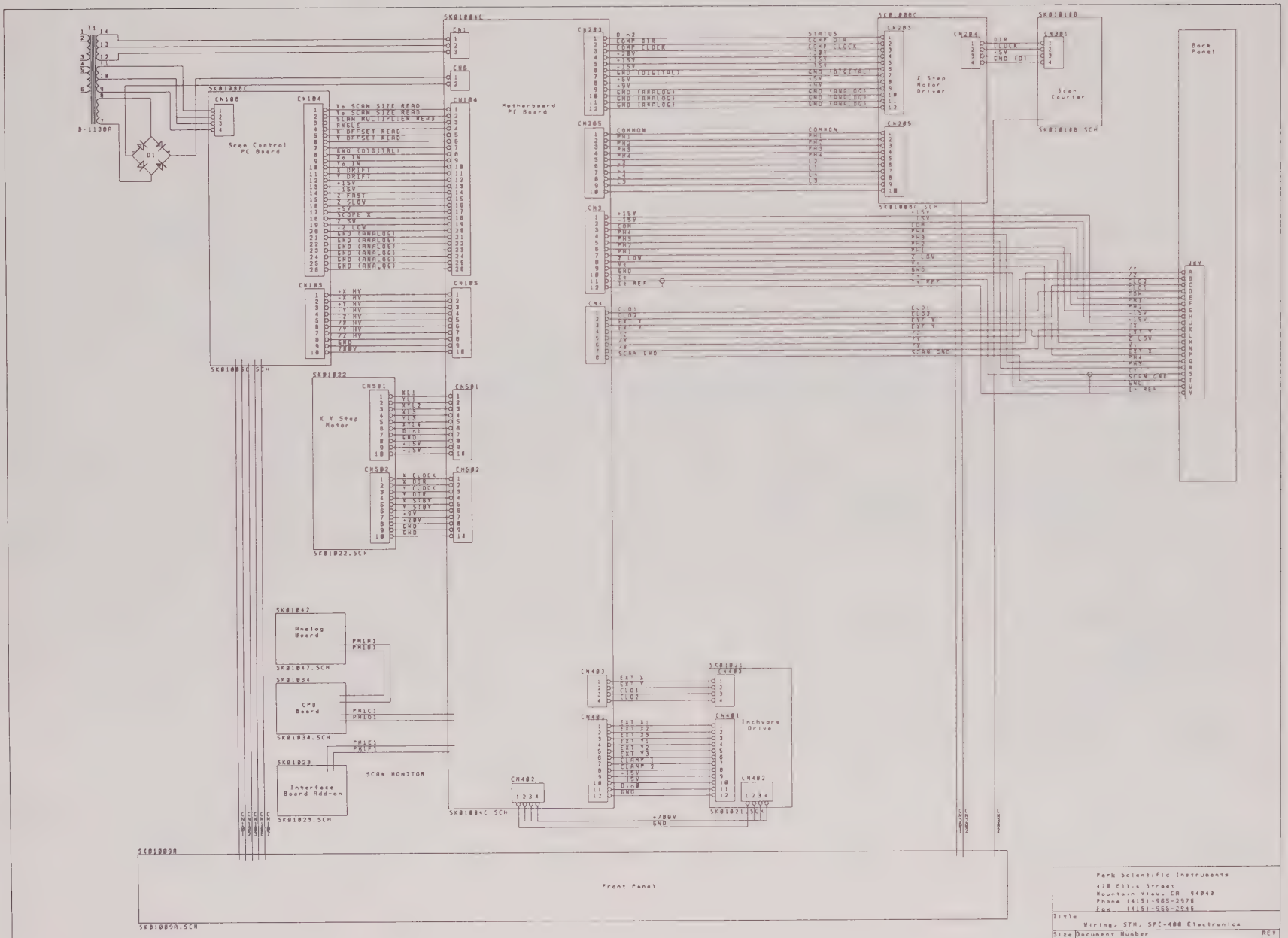
Title	Schematic, STM-5U2-210, Feedback
Size B	Document Number SK01024A
REV A	
Date: June 7, 1990	Sheet 3 of 3


Motherboard PC Board
Scan Control PC Board
Z Step Motor Driver
Scan Counter
Back Panel
X Y Step Motor
Analog Board
CPU Board
Interface Board Add-on
SCAN MONITOR
Inchworm Drive
Front Panel
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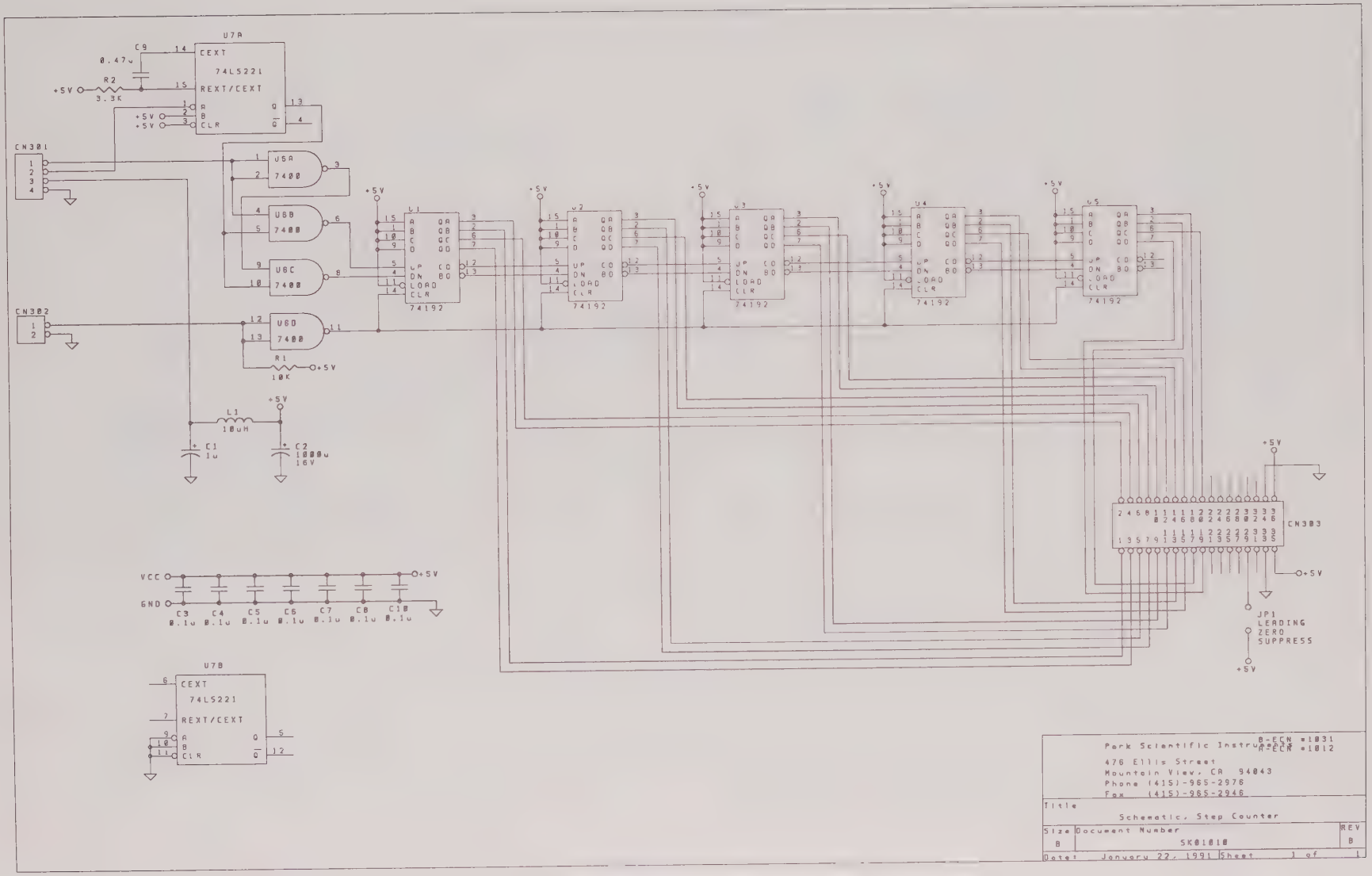
Title
Wiring, STM, SPC-400 Electronics
Size C
Document Number
SK01009A
REV A
Date: March 29, 1991 Sheet 1 of 8


U7A
74LS221
CEXT
REXT/CEXT
A
B
CLR
Q
C9
0.47u
R2
3.3K
+5V
CN301
U5A
U5B
U5C
U5D
7400
CN302
U1
U2
U3
U4
U5
74192
UP
DN
LOAD
CLR
CO
BO
R1
10K
L1
10uH
C1
1u
C2
1000u
16V
VCC
GND
C3
C4
C5
C6
C7
C8
C10
0.1u
CN303
JP1
LEADING
ZERO
SUPPRESS
U7B
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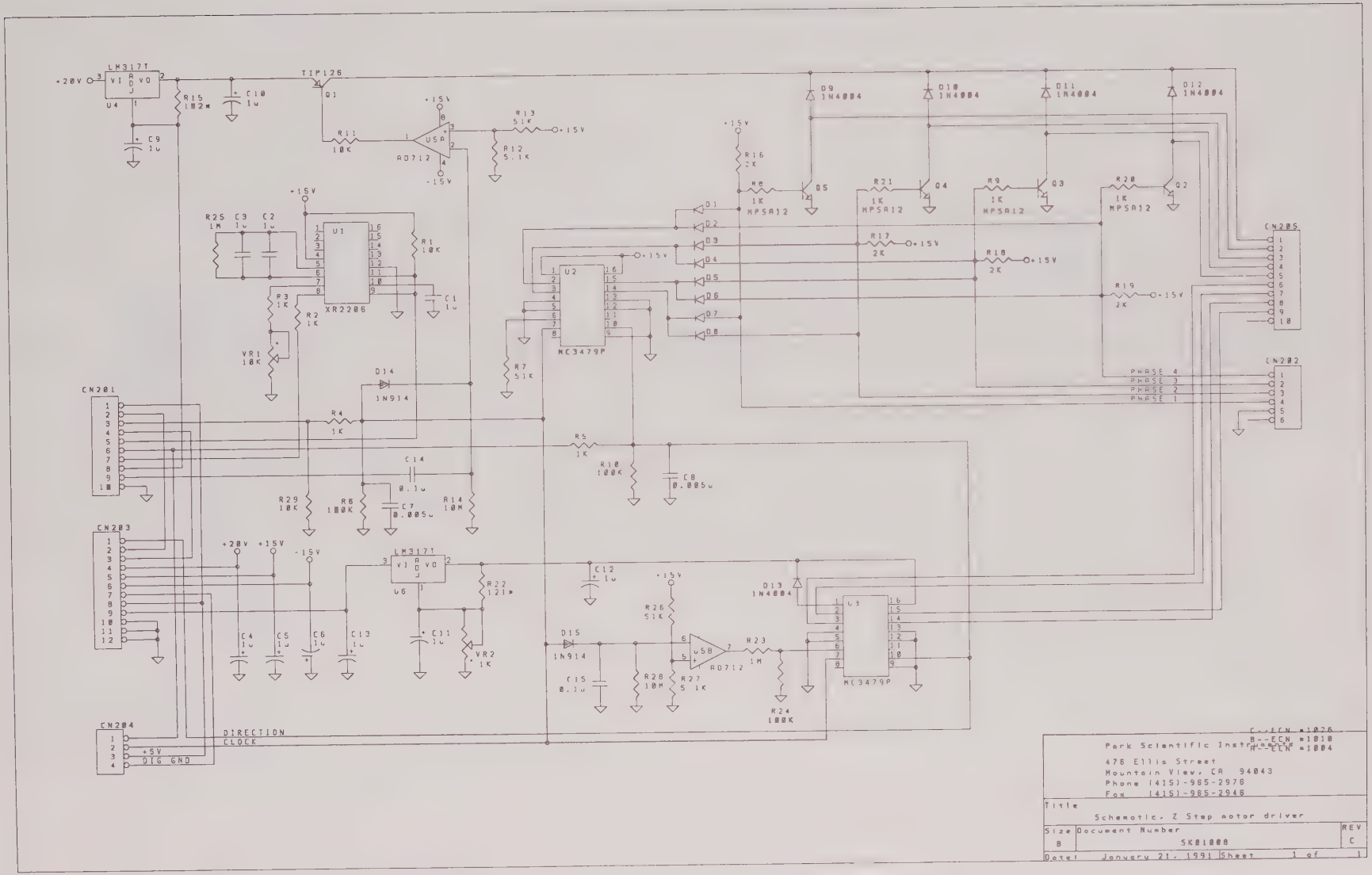
B-ECN =1031
A-ECN =1012
Title
Schematic, Step Counter
Size
B
Document Number
SK01818
REV
B
Date: January 22, 1991
Sheet 1 of 1


LM317T
TIP126
AD712
XR2206
MC3479P
1N914
1N4004
MPSA12
CN201
CN202
CN203
CN204
CN205
DIRECTION
CLOCK
+5V
DIG GND
PHASE 4
PHASE 3
PHASE 2
PHASE 1
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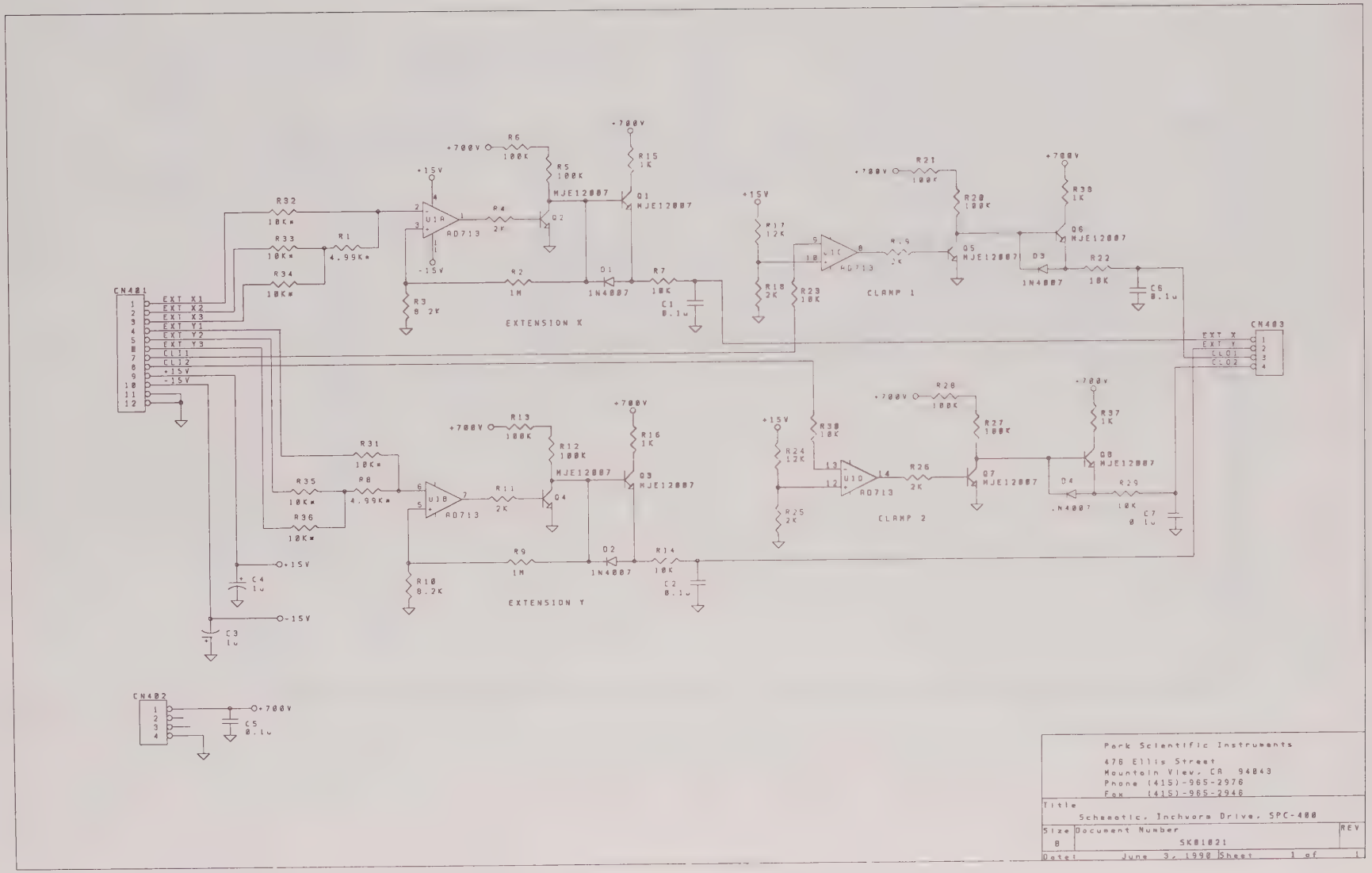
Mountain View, CA 94043
Phone (415)-965-2976
Fax (415)-965-2948
Title
Schematic, Z Step motor driver
Size B
Document Number SK81008
REV C
Date: January 21, 1991 Sheet 1 of 1



Park Scientific Instruments	
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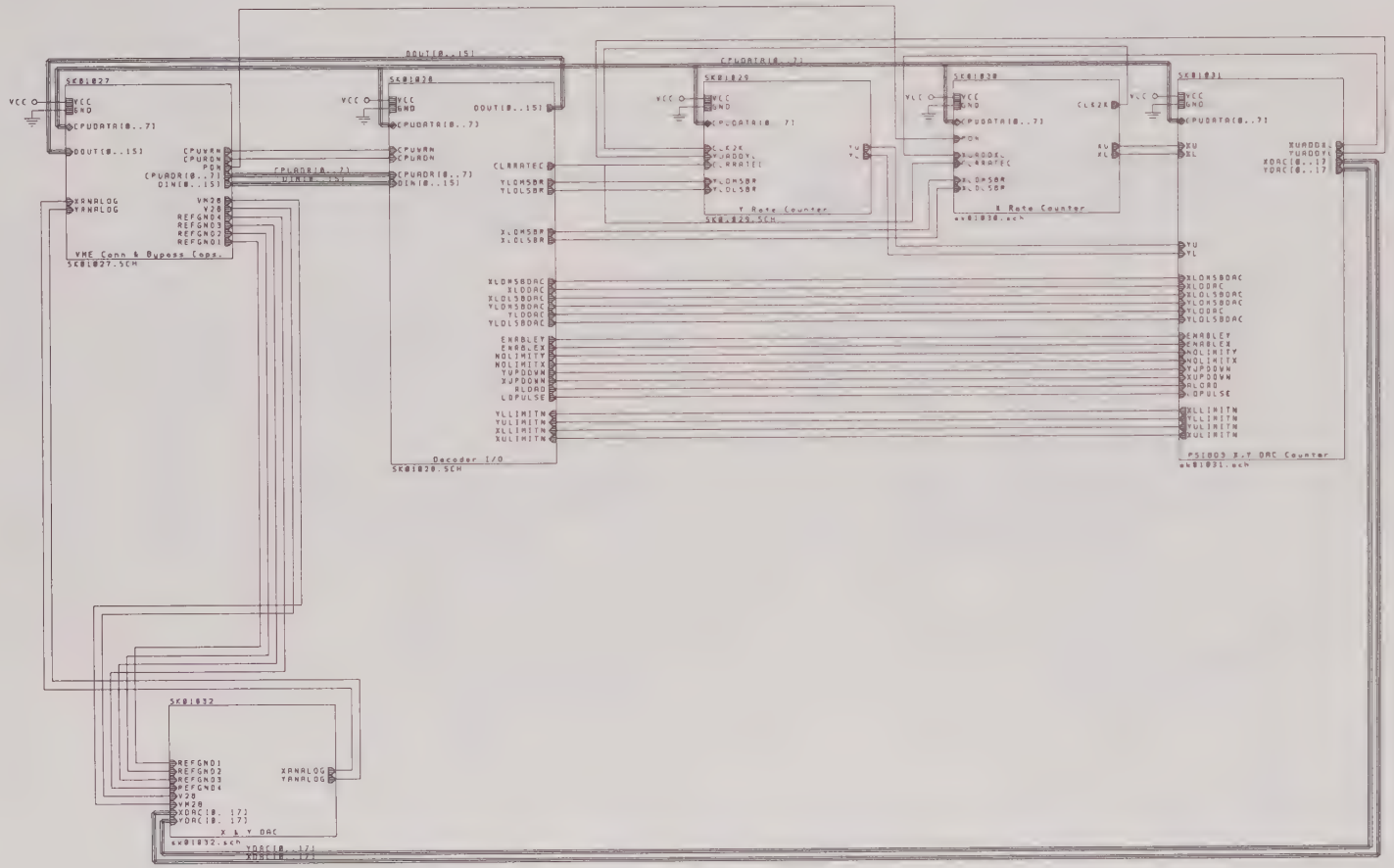
Title: Schematic, Inchworm Drive, SPC-400	
Size: B	Document Number: SK01021 REV
Date: June 3, 1990	Sheet 1 of 1



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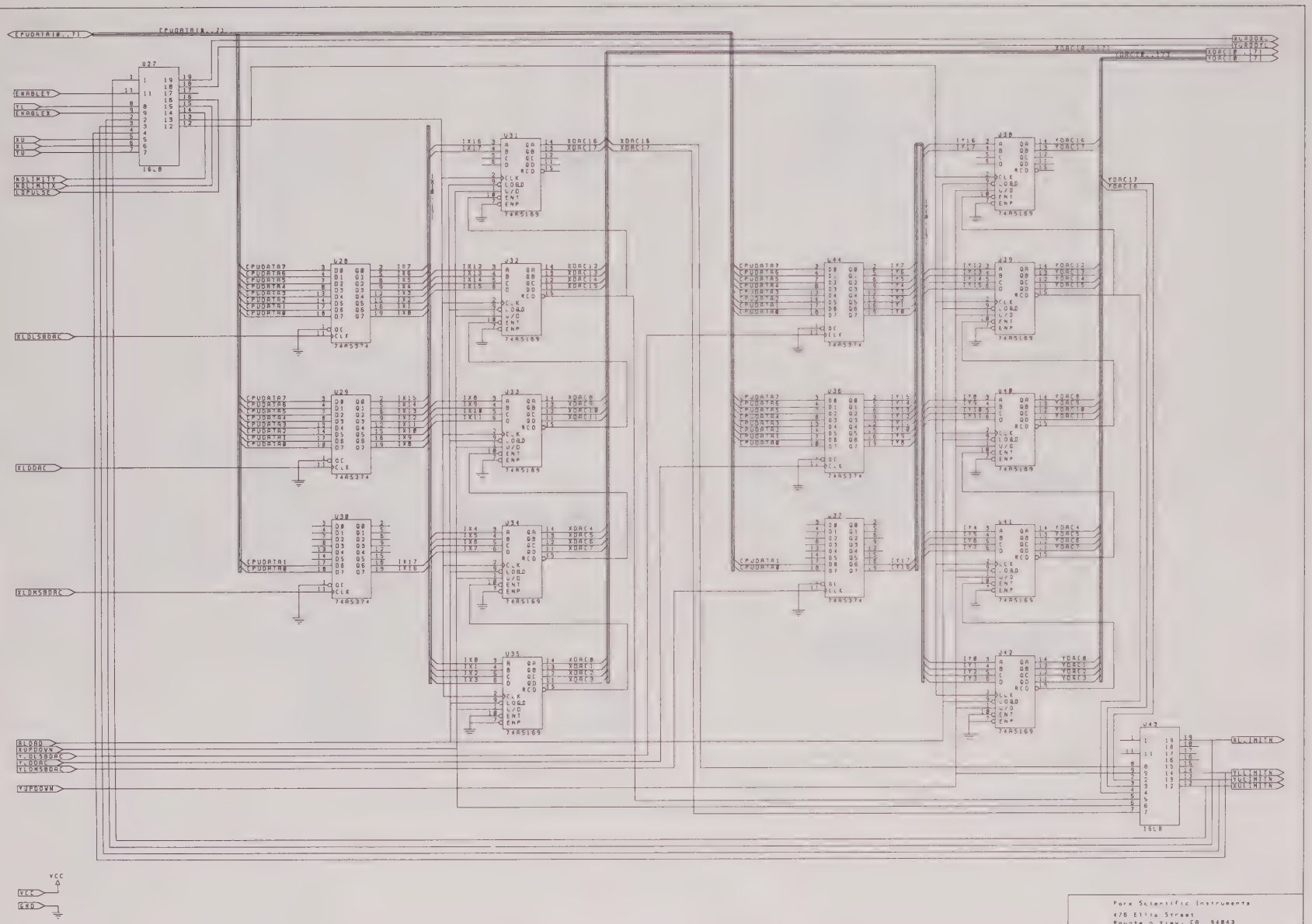
Title
Schematic, Interface Board

Size	Document Number	REV
C	SK01825	B

Date: May 3, 1990 Sheet 1 of 8


CPUDATA[0..7]
ENABLEY
YL
ENABLEX
XU
XL
YU
NOLIMITY
NOLIMITX
INPULSE
XLDLSBDAC
XLDDAC
XLDMSBDAC
YUPDOWN
XL_LIMIT
YL_LIMIT
YU_LIMIT
VCC
GND
74AS169
74AS374
74AS244
16L8
Park Scientific Instruments
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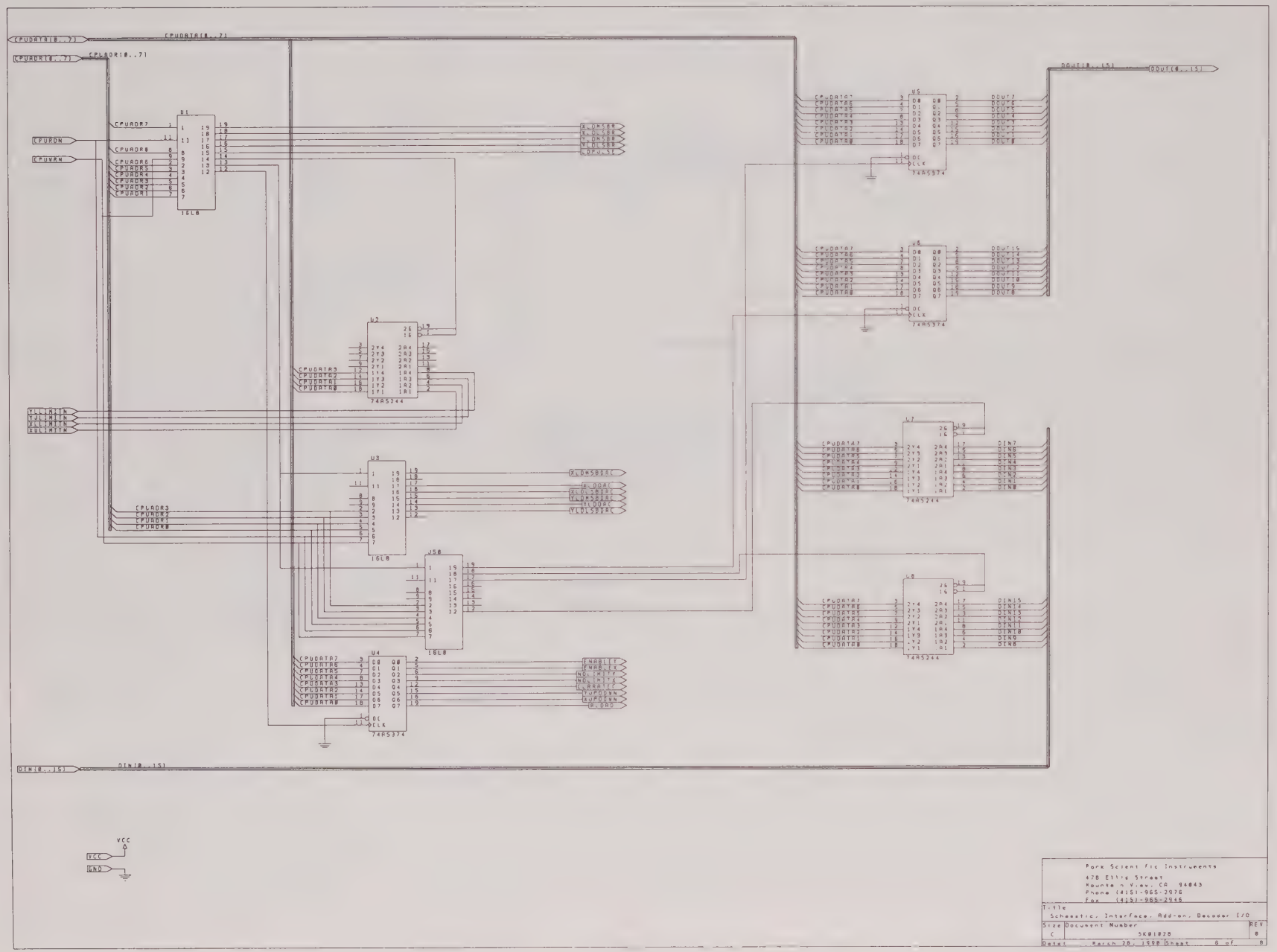
Phone (415)-965-2978
Fax (415) 965-2946
Title
Schemat a, Interface, Add on, X Y Dac Counte
Size Document Number REV
C SK01831 0
Date: March 30, 1990 Sheet 2 of 8



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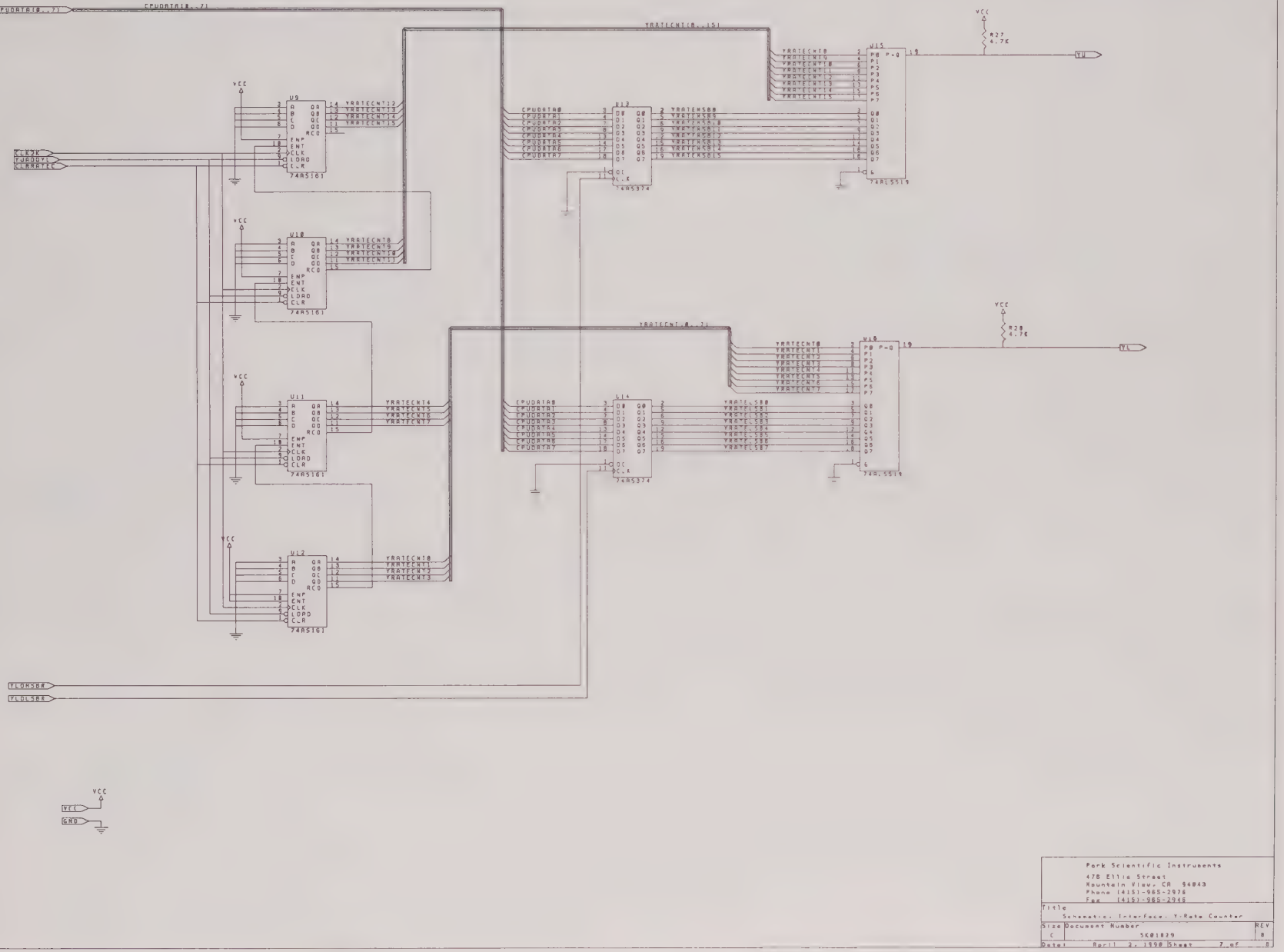
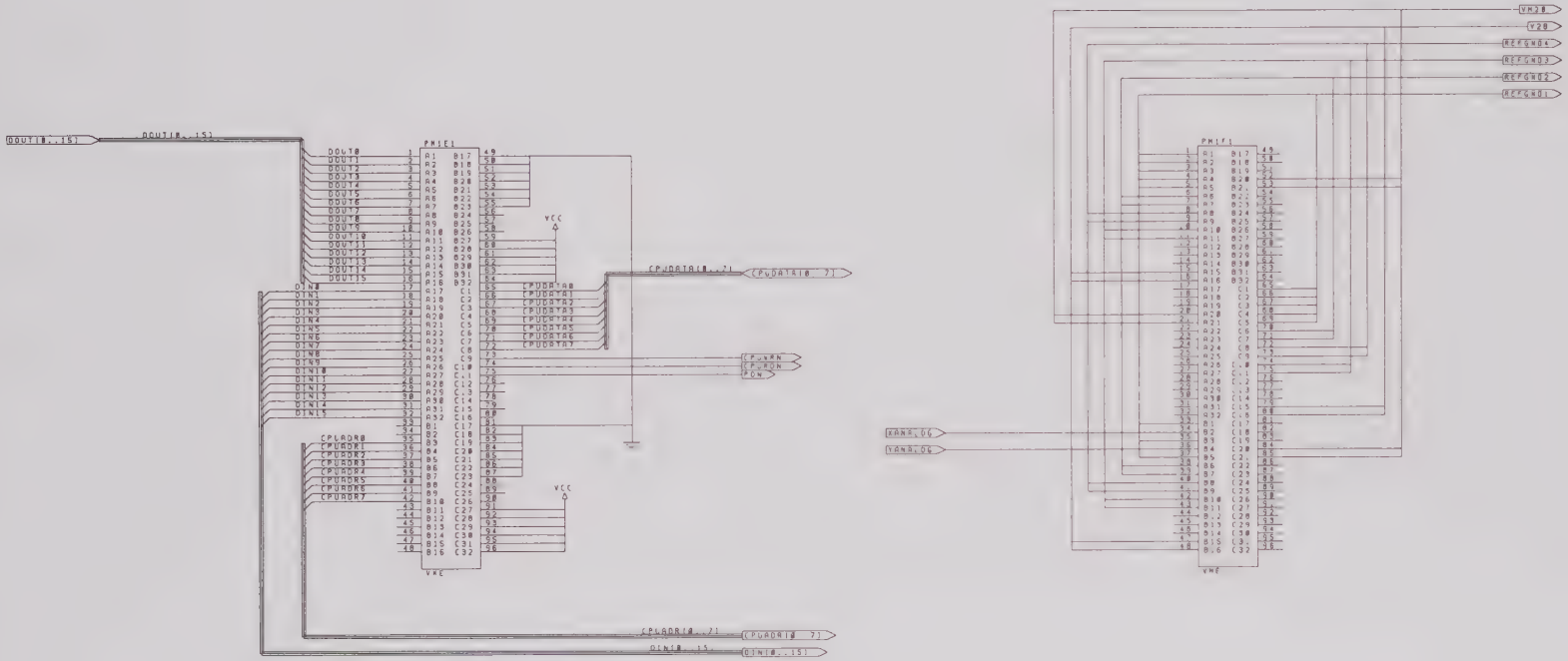
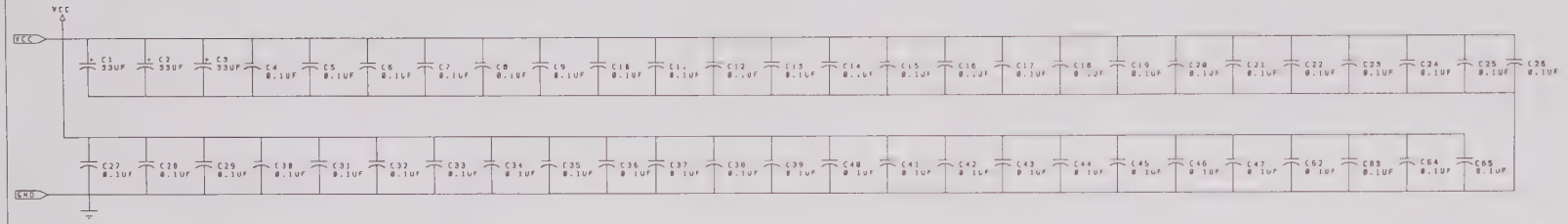
Title Schematic, Interface, Add-on, Decoder I/O		
Size C	Document Number SK#1020	REV B
Date: March 20, 1990 Sheet 6 of 8		



Pork Scientific Instruments 478 Ellis Street Mountain View, CA 94043 Phone (415)-965-2978 Fax (415)-965-2945		
Title: Schematic, Interface, Y-Rate Counter		
Size: C	Document Number: SK01829	REV: B
Date: April 2, 1990	Sheet 7 of 8	





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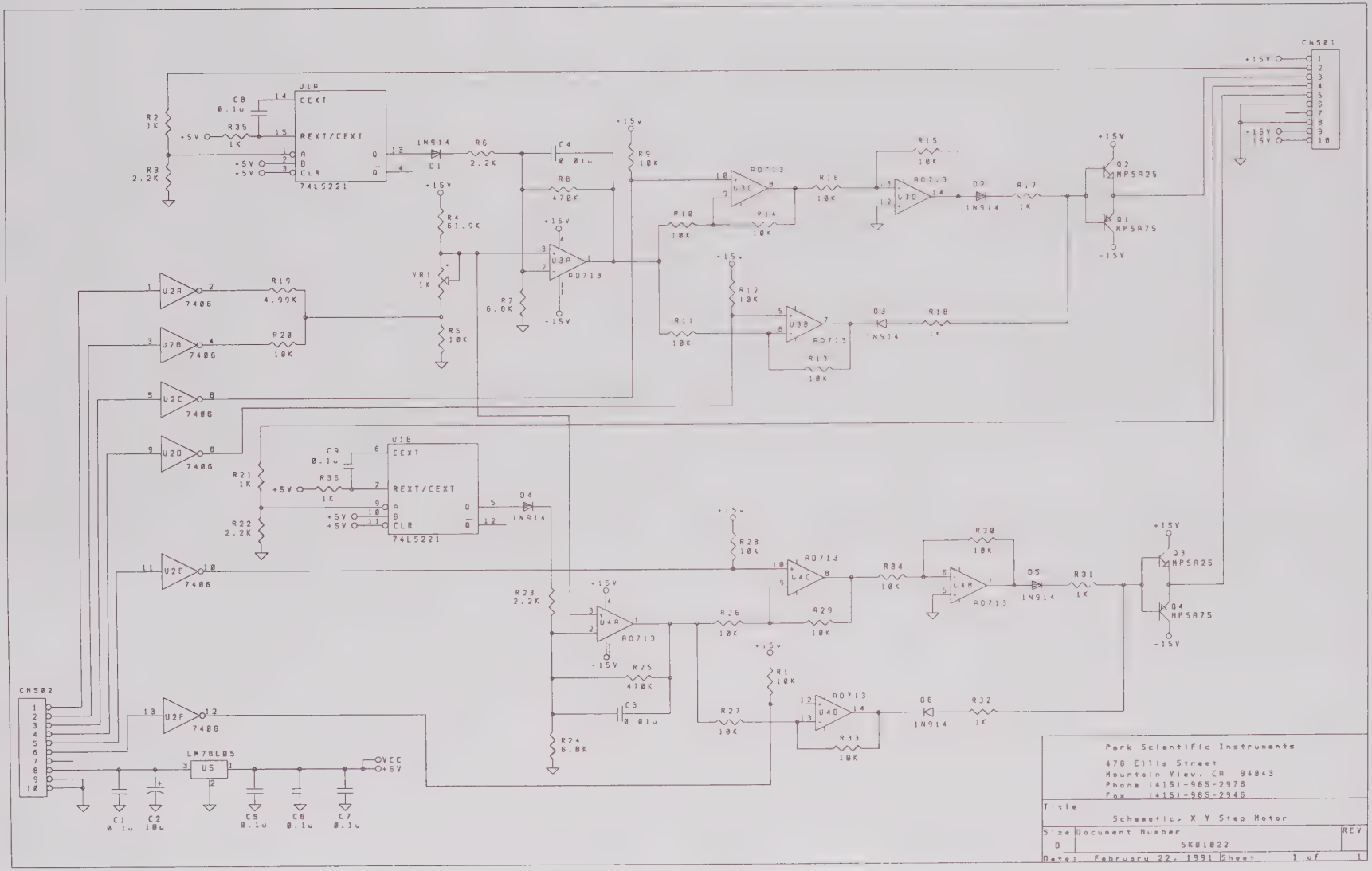
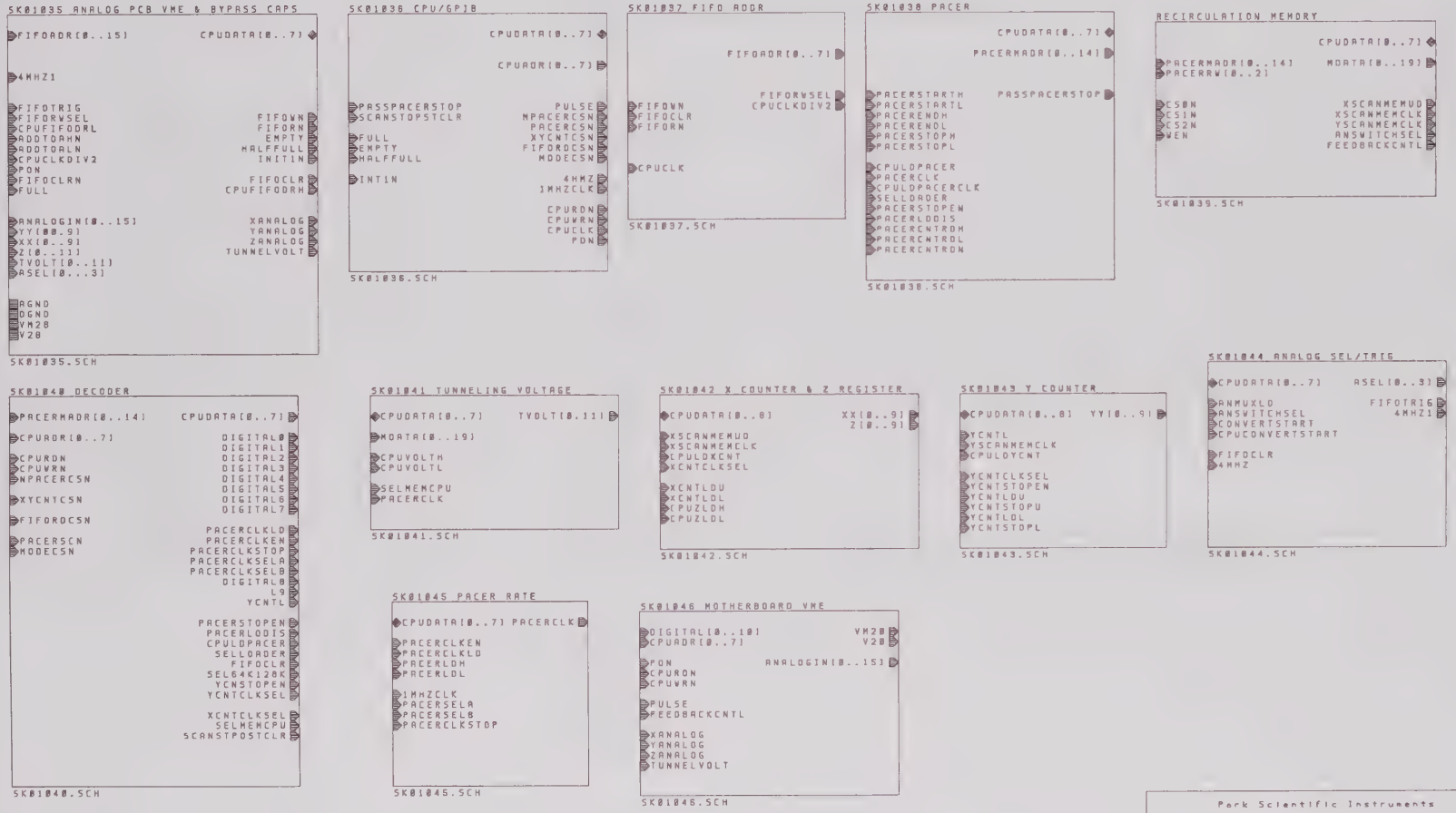
Title	Schematic, Interface, VME & Bypass Caps	
Size C	Document Number SK01827.SCH	REV B
Date: May 3, 1988	Sheet 5 of 8	


CN501
CN502
U1A
U1B
74LS221
U2A
U2B
U2C
U2D
U2E
U2F
7406
U3A
U3B
U3C
U3D
U4A
U4B
U4C
U4D
AD713
AD7.3
U5
LM78L05
1N914
MPSA25
MPSA75
Q1
Q2
Q3
Q4
D1
D2
D3
D4
D5
D6
+15V
-15V
+5V
VCC
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22
R23
R24
R25
R26
R27
R28
R29
R30
R31
R32
R33
R34
R35
R36
VR1
C1
C2
C3
C4
C5
C6
C7
C8
C9
Park Scientific Instruments
478 Ellis Street
Mountain View, CA 94043
Phone (415)-965-2976
Fax (415)-965-2946
Title
Schematic, X Y Step Motor
Size
B
Document Number
SK81022
REV
Date: February 22, 1991 Sheet 1 of 1



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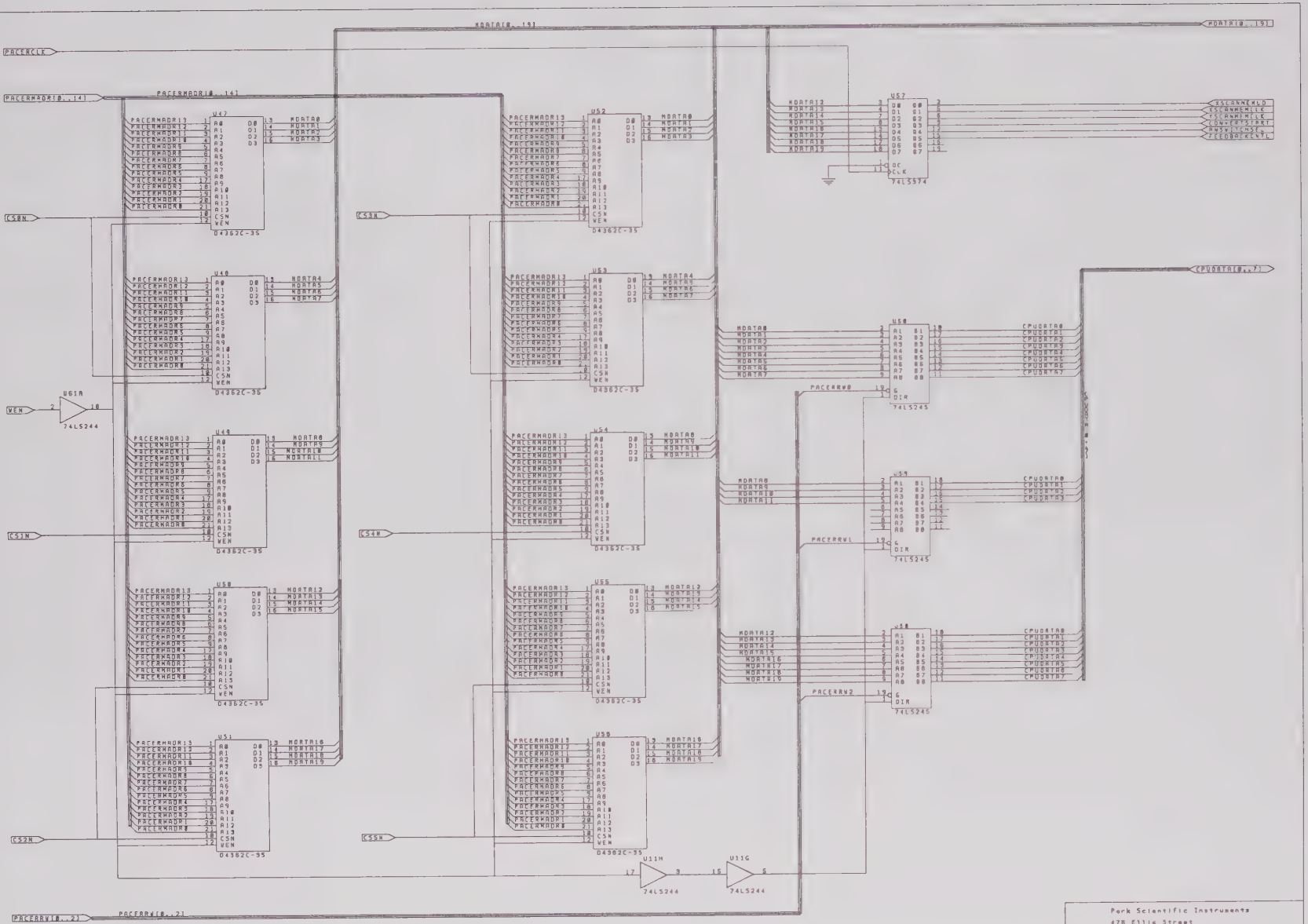
Title	Schematic, CPU, GPIB PCB	
Size B	Document Number SK01034	REV
Date: March 29, 1991	Sheet 12 of 12	


PACERCLK
PACERMADR[0..14]
MDATA[0..19]
CPUDATA[0..7]
CS0N
CS1N
CS2N
CS3N
CS4N
CS5N
VEN
PACERRV[0..2]
U47
U48
U49
U50
U51
U52
U53
U54
U55
U56
U57
U58
U59
U61A
U11M
U11G
74LS244
74LS245
74LS374
D4362C-35
Park Scientific Instruments
478 Ellis Street
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Phone (415)-965-2976
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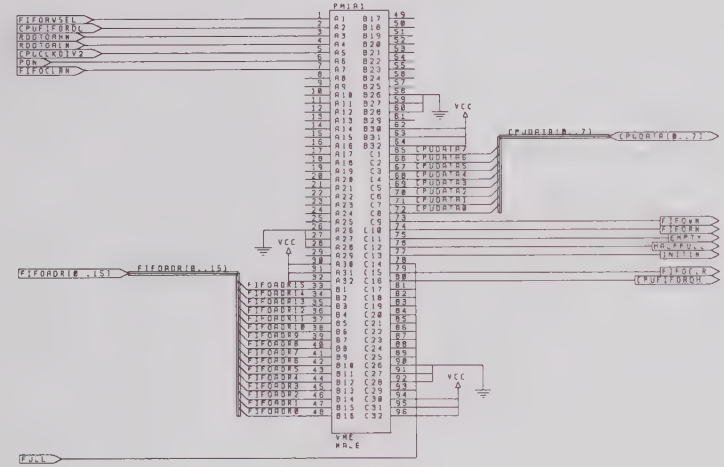
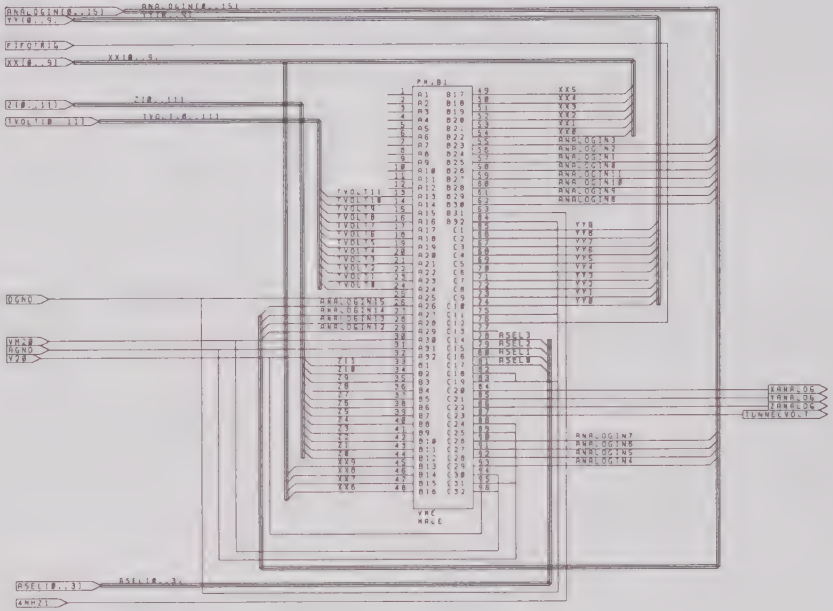
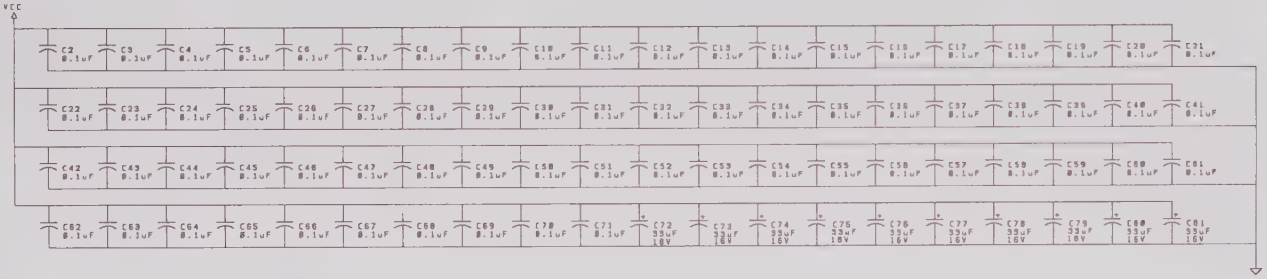
Title
RECIRCULATION MEMORY
Size
C
Document Number
SK01039
REV
C
Date: May 18, 1990 Sheet 5 of 12







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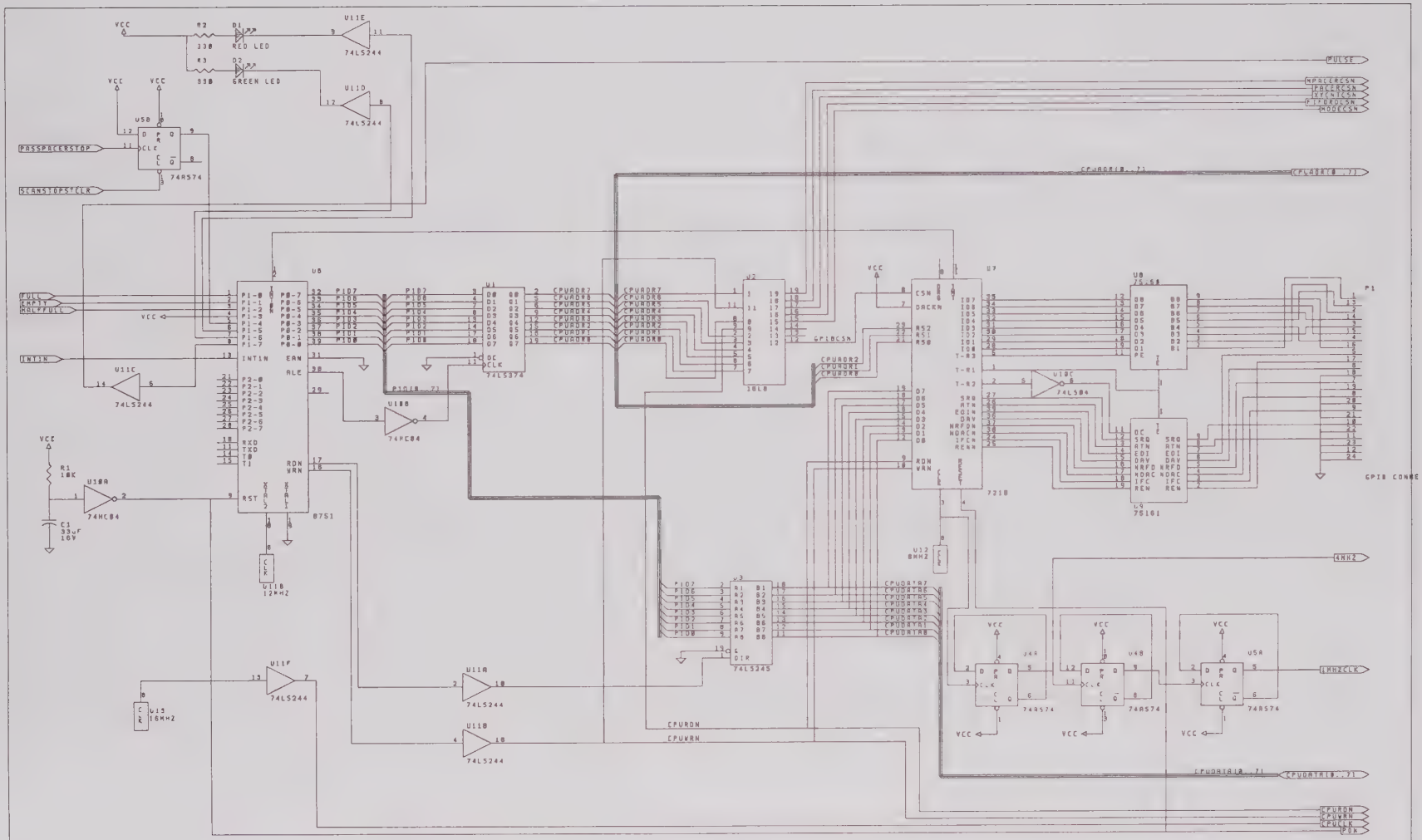
Title: VME CONNECTORS & BYPASS CAPS.

Size	Document Number	REV
C	SC01835	C

Date: Nov 10, 1990 Sheet 1 of 12


VCC
330
RED LED
GREEN LED
74LS244
74AS74
PASSPACERSTOP
SCANSTOPS*CLR
PULSE
MPACERCSN
PACERCSN
IXFCNTCSN
PTORDLSN
MODECSN
CPUADR[8..7]
CPUADR[8..7]
CPUADR7
CPUADR6
CPUADR5
CPUADR4
CPUADR3
CPUADR2
CPUADR1
CPUADR8
GPIBCSN
74LS374
74LS5
74LS84
74HC04
74LS5245
7210
75161
GPIB CONNE
P1
FULL
EMPTY
HALFFULL
INTIN
P1018..7]
8751
11.0592MHZ
4MHZ
4MHZCLK
CPURDN
CPUWRN
CPUDATA[8..7]
CPUDATA[8..7]
CPUCLK
PSN
Park Scientific Instruments
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Phone (415)-965-2976
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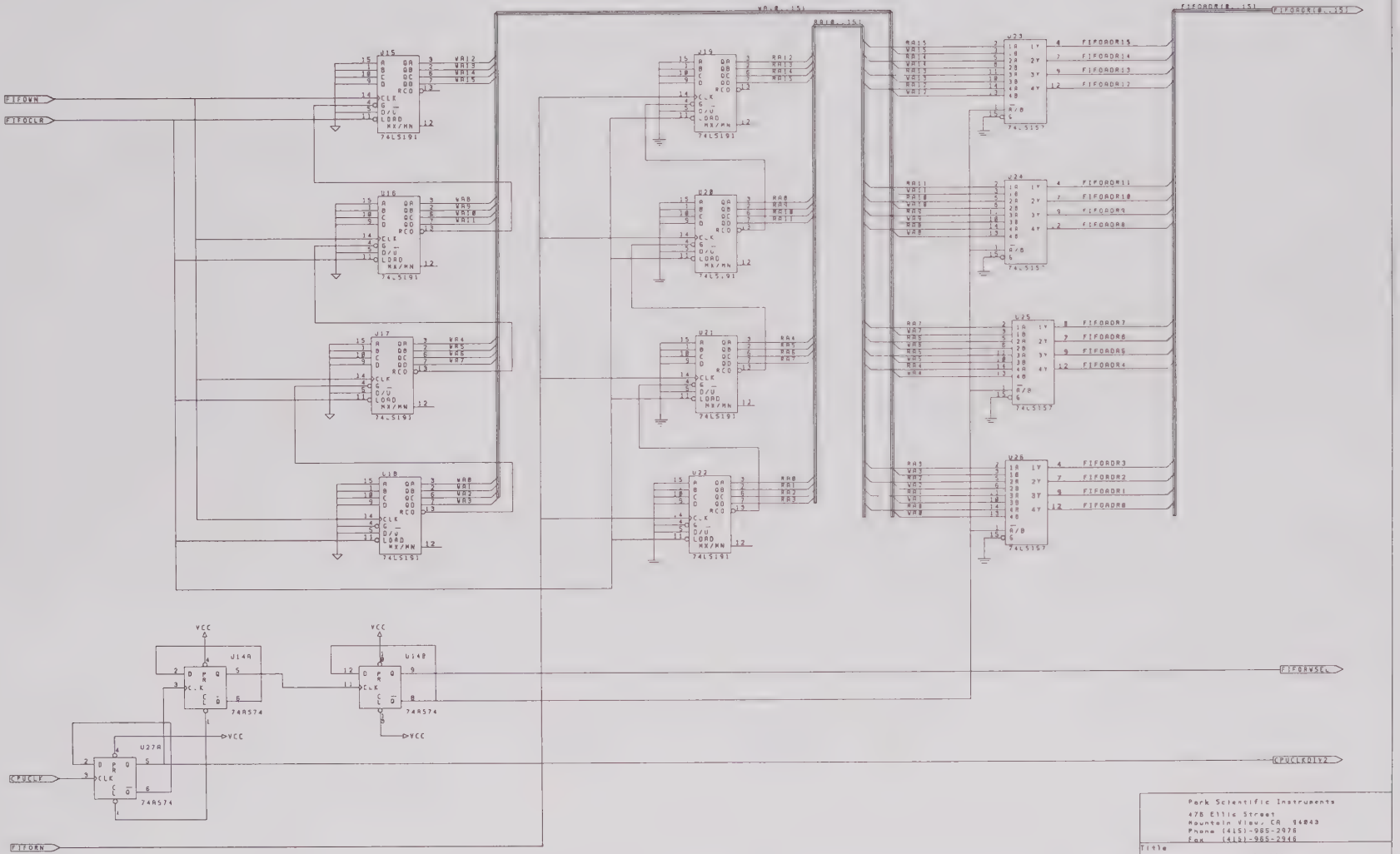
Title
CPU/GPIB
Size C
Document Number
SK01038
REV C
Date: May 18, 1990 Sheet 2 of 12


FIFOWN
FIFOCLR
U15
U16
U17
U18
74LS191
U19
U20
U21
U22
74LS157
U23
U24
U25
U26
FIFOADR15
FIFOADR14
FIFOADR13
FIFOADR12
FIFOADR11
FIFOADR10
FIFOADR9
FIFOADR8
FIFOADR7
FIFOADR6
FIFOADR5
FIFOADR4
FIFOADR3
FIFOADR2
FIFOADR1
FIFOADR0
FIFOADR[8..15]
FIFOAWSEL
CPUCLK
CPUCLK1X2
VCC
U14A
U14B
U27A
74AS74
Park Scientific Instruments
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Phone (415)-965-2976
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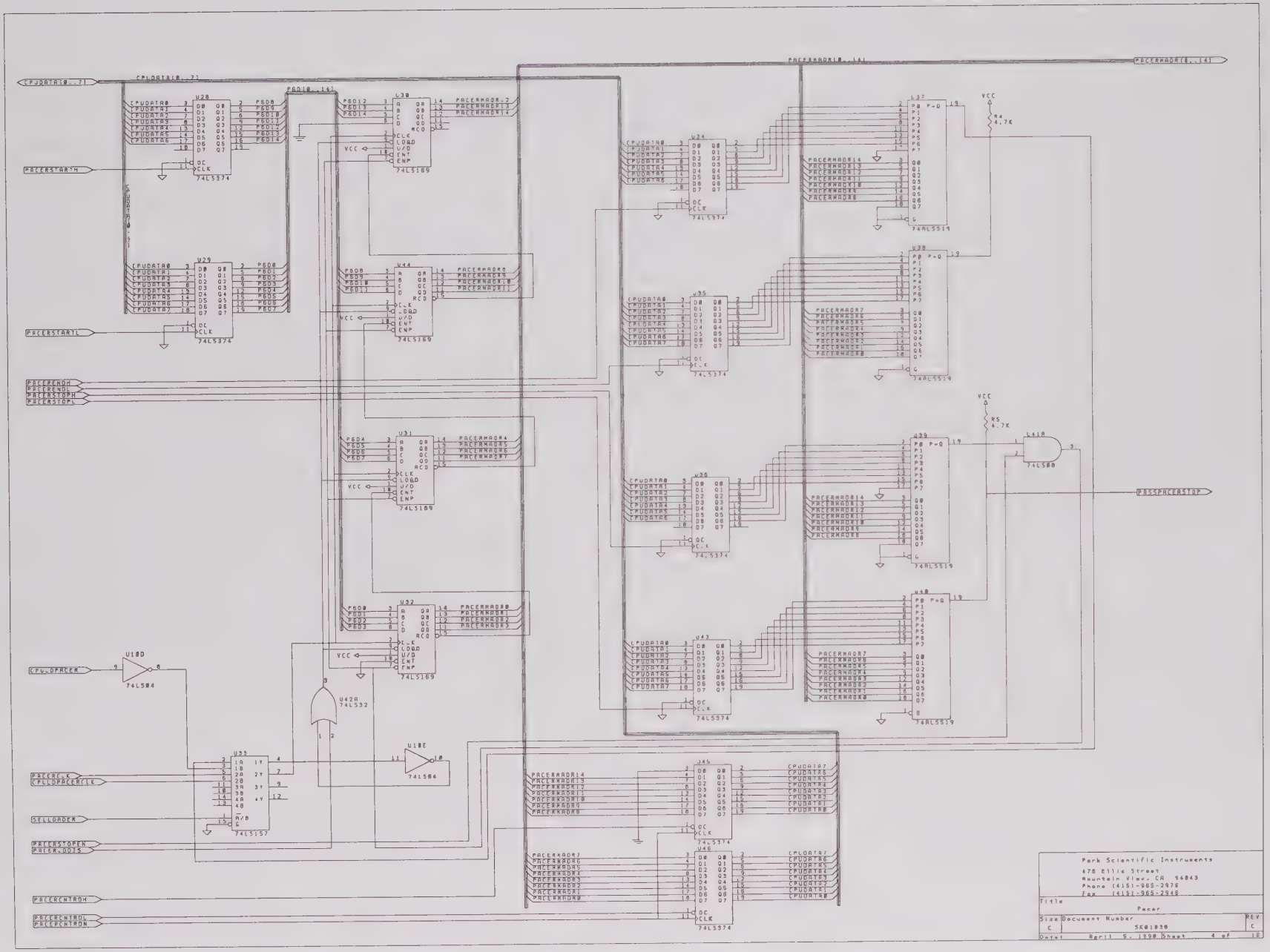
Title
FIFO ADR
Size C
Document Number 5KB1837
REV C
Date: May 10, 1990 Sheet 3 of 12


CPUDATA[0..7]
PACERSTARTH
PACERSTARTL
PACERENDH
PACERENDL
PACERSTOPH
PACERSTOPL
PACERMADR[0..14]
PASSPACERSTOP
CPU_DPACER
PACERCLK
CPLLDPACERCLK
SELLOADER
PACERSTOPEN
PACER_DOIS
PACERCNTROH
PACERCNTROL
PACERCNTRON
VCC
74LS374
74LS169
74LS519
74LS157
74LS04
74LS32
74LS08
Park Scientific Instruments
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Title
Pacer
Size C
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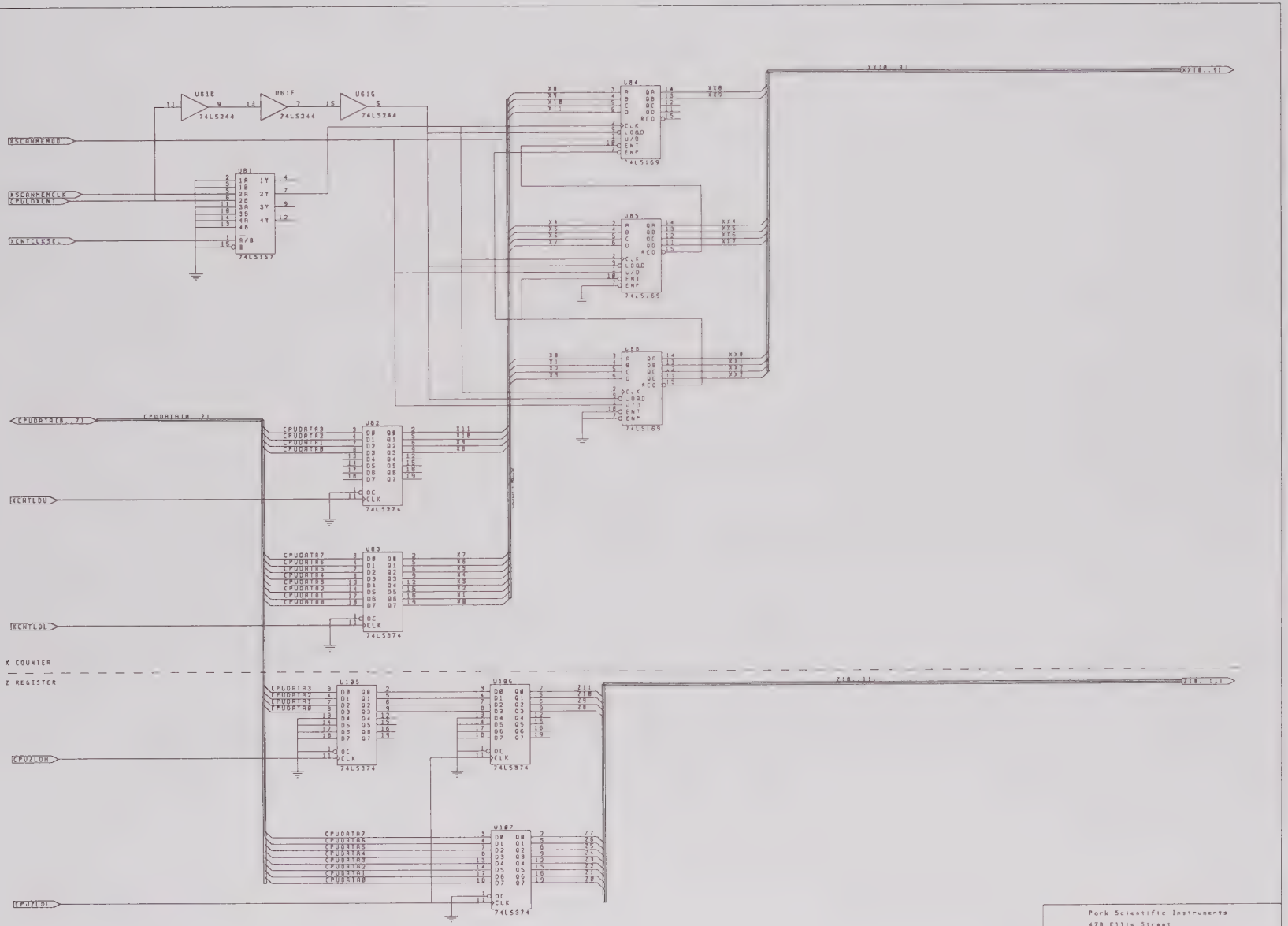
REV C
Date: April 5, 1990 Sheet 4 of 18


U61E
74LS244
U61F
74LS244
U61G
74LS244
U84
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U86
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U81
74LS157
U82
74LS374
U83
74LS374
U105
74LS374
U106
74LS374
U107
74LS374
XSCANNENCLK
CPULDXCNT
XCNTCLKSEL
XCNTLDU
XCNTLDL
CPUZLDH
CPUZLDL
X COUNTER
Z REGISTER
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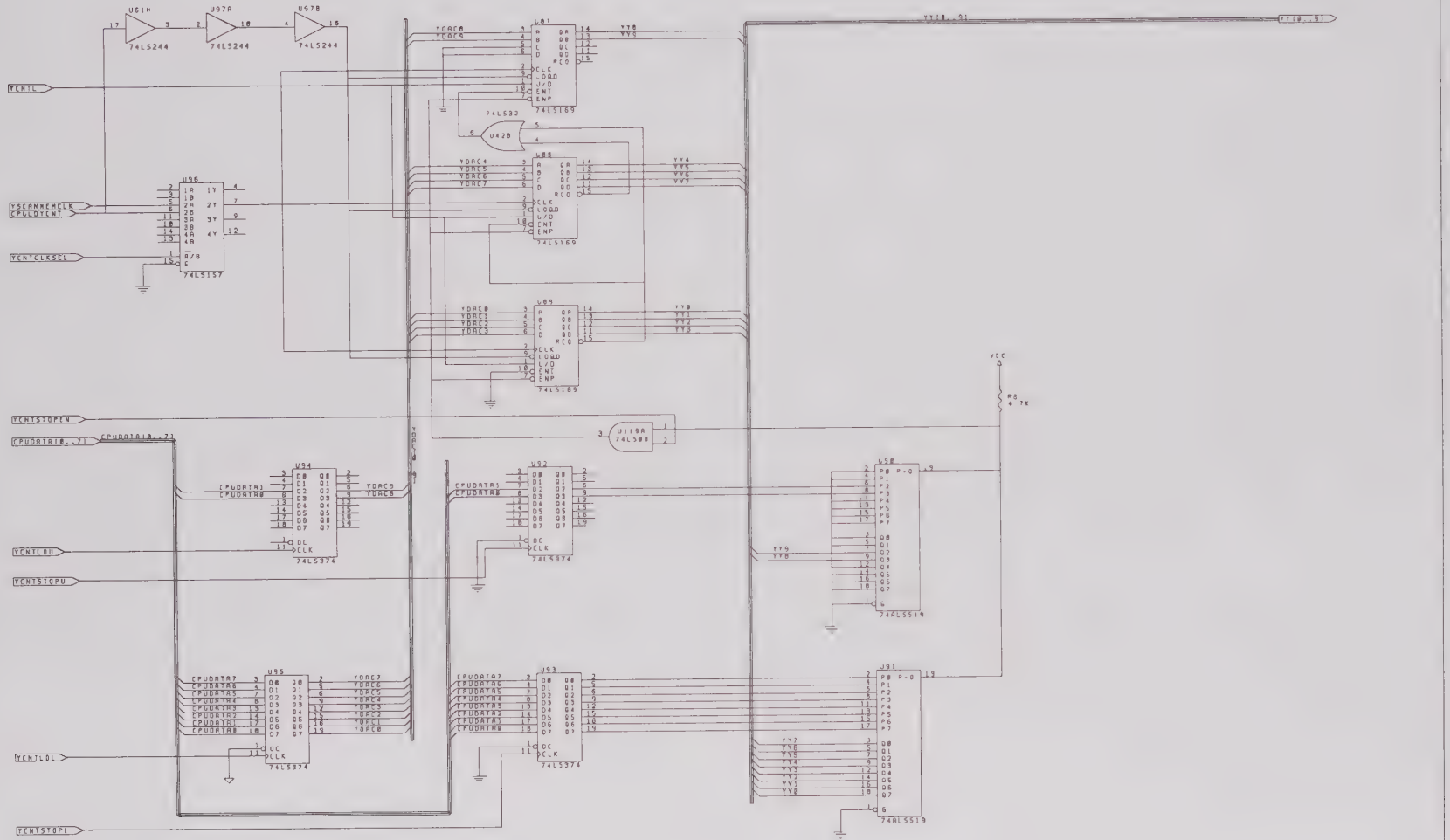
Title
X COUNTER & Z REGISTER
Size Document Number
C
5K01842
REV
C
Date: April 6, 1990 Sheet 8 of 12



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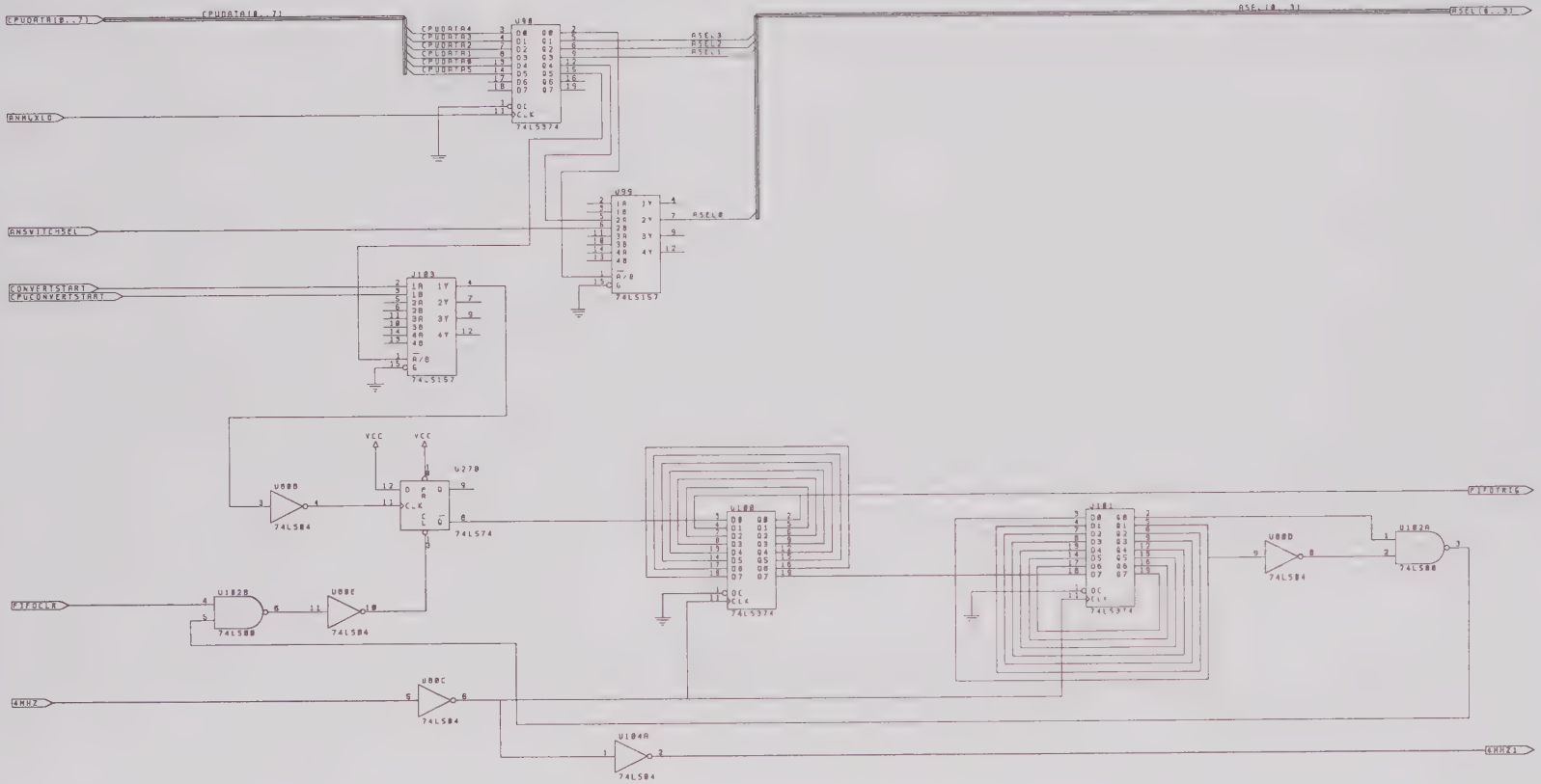
Title
Y COUNTER

Size	Document Number	REV
C	SK01843	C

Date: May 18, 1990 Sheet 9 of 12



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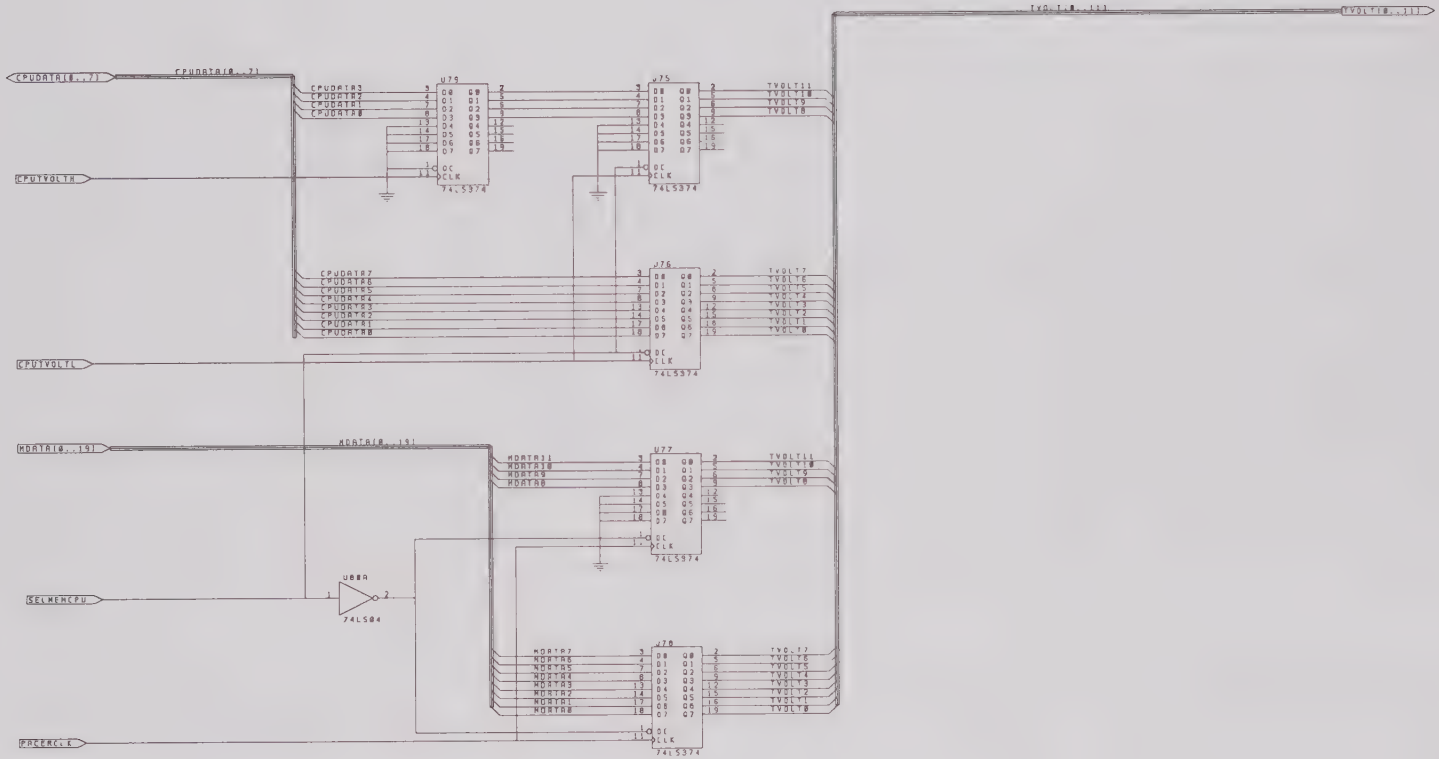
Title
ANALOG SEL/TRIG

Size	Document Number	REV
C	SK01044	C

Date: May 10, 1990 Sheet 10 of 12



Park Scientific Instruments	
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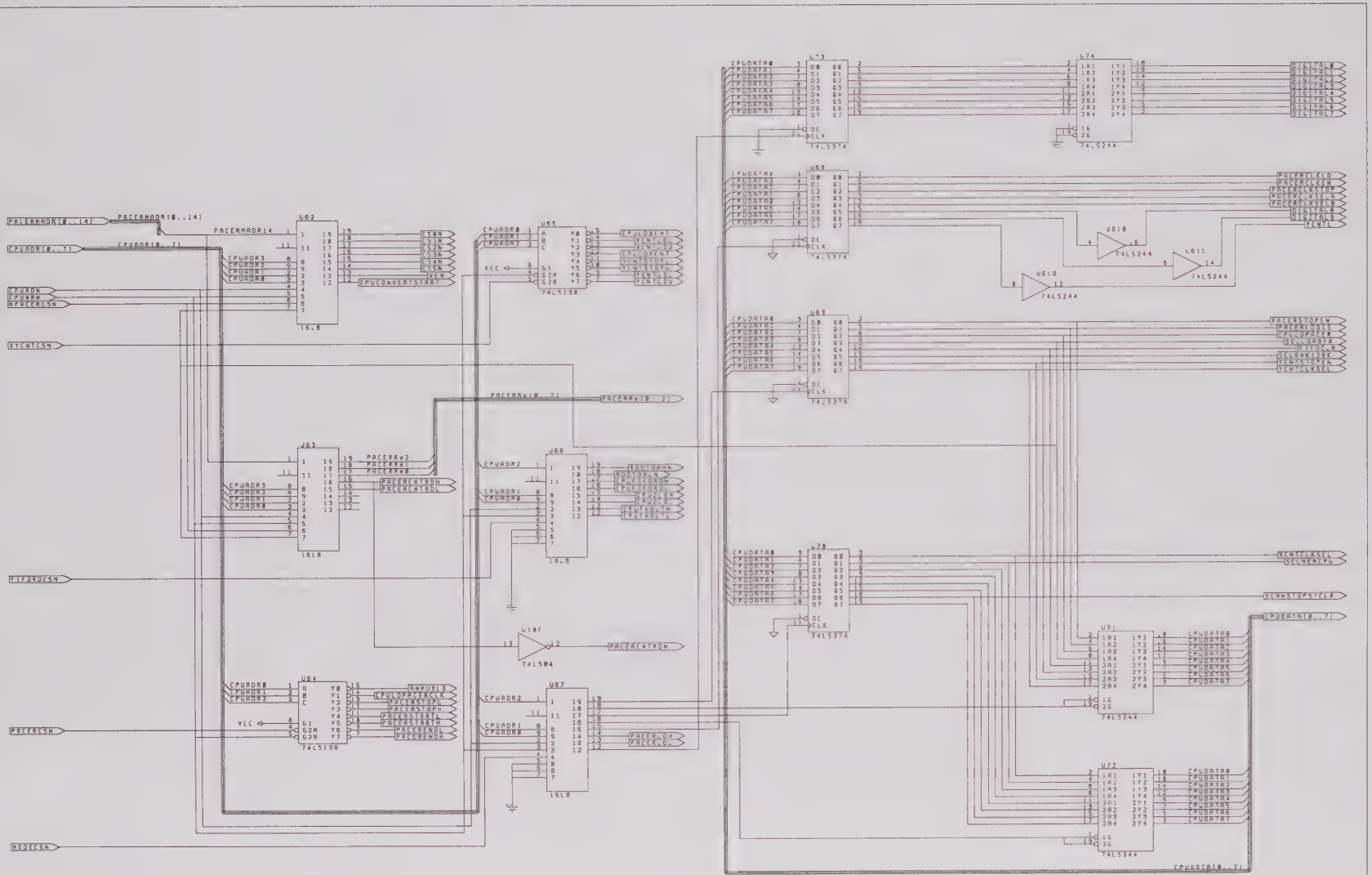
Fax (415)-965-2948	
Title	TUNNELING VOLTAGE
Size C	Document Number SK01041 REV C
Date: April 5, 1998	Sheet 7 of 12


PACERMADR[0..14]
CPUADR[0..7]
CPURDN
CPUWRN
MPACERCSN
XYCNTCSN
PITPROCSN
PACERCSN
MOSECSN
U62
U63
U64
U65
U66
U67
U68
U69
U70
U71
U72
74LS374
74LS244
74LS138
74LS04
CPUDATA[0..7]
Park Scientific Instruments
476 Ellis Street
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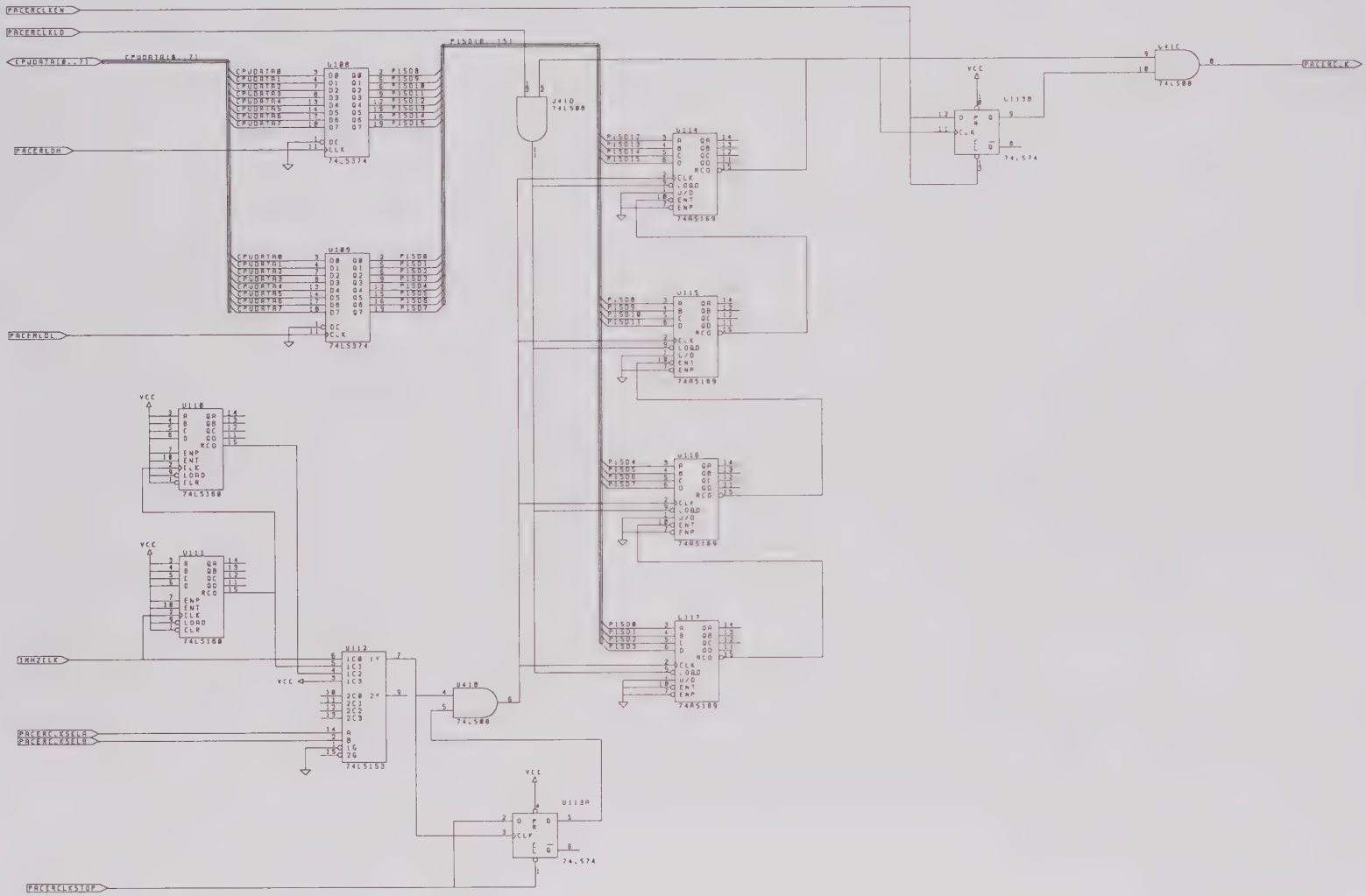
Fax (415)-965-2946
Title
DECODER
Size Document Number
SK0184D
REV
C
Date: April 5, 1990 Sheet 6 of 12



Park Scientific Instruments	
470 Ellis Street	
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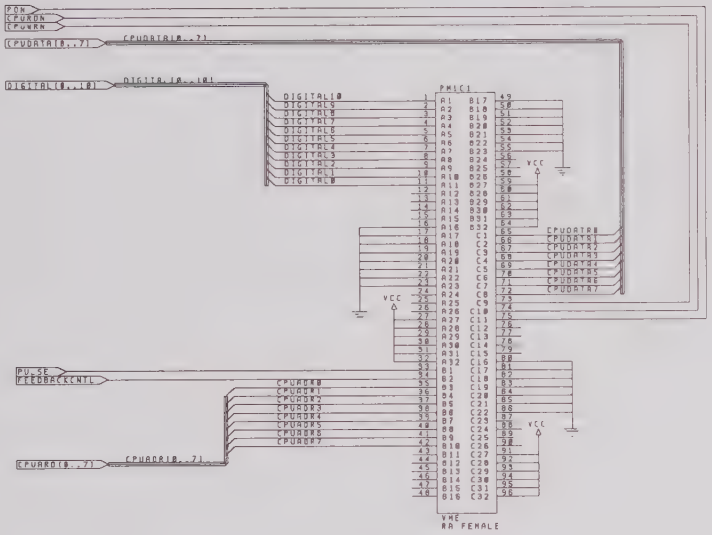
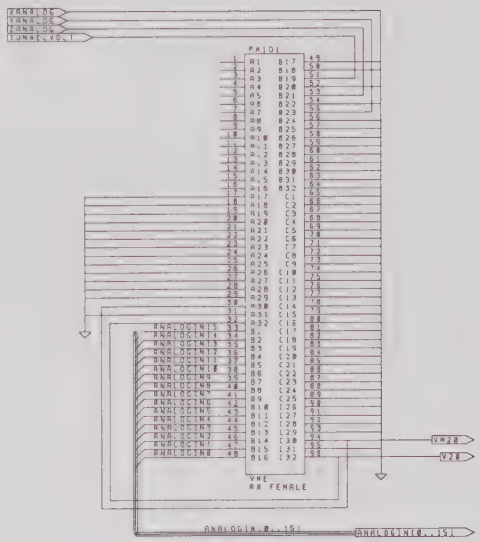
Phone (415)-965-2976	
Fax (415)-965-2546	
Title	Pacer Rate
Size C	Document Number SK01045 REV C
Date: April 6, 1990 Sheet 11 of 12	





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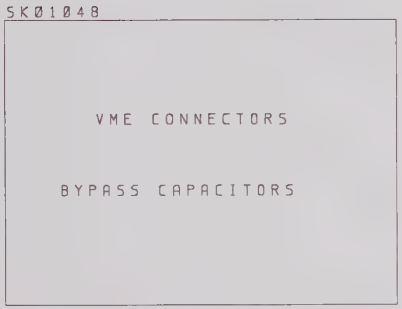
Title
Motherboard VME

Size	Document Number	REV
C	SK81848	C

Date: May 18, 1990 Sheet 18 of 32



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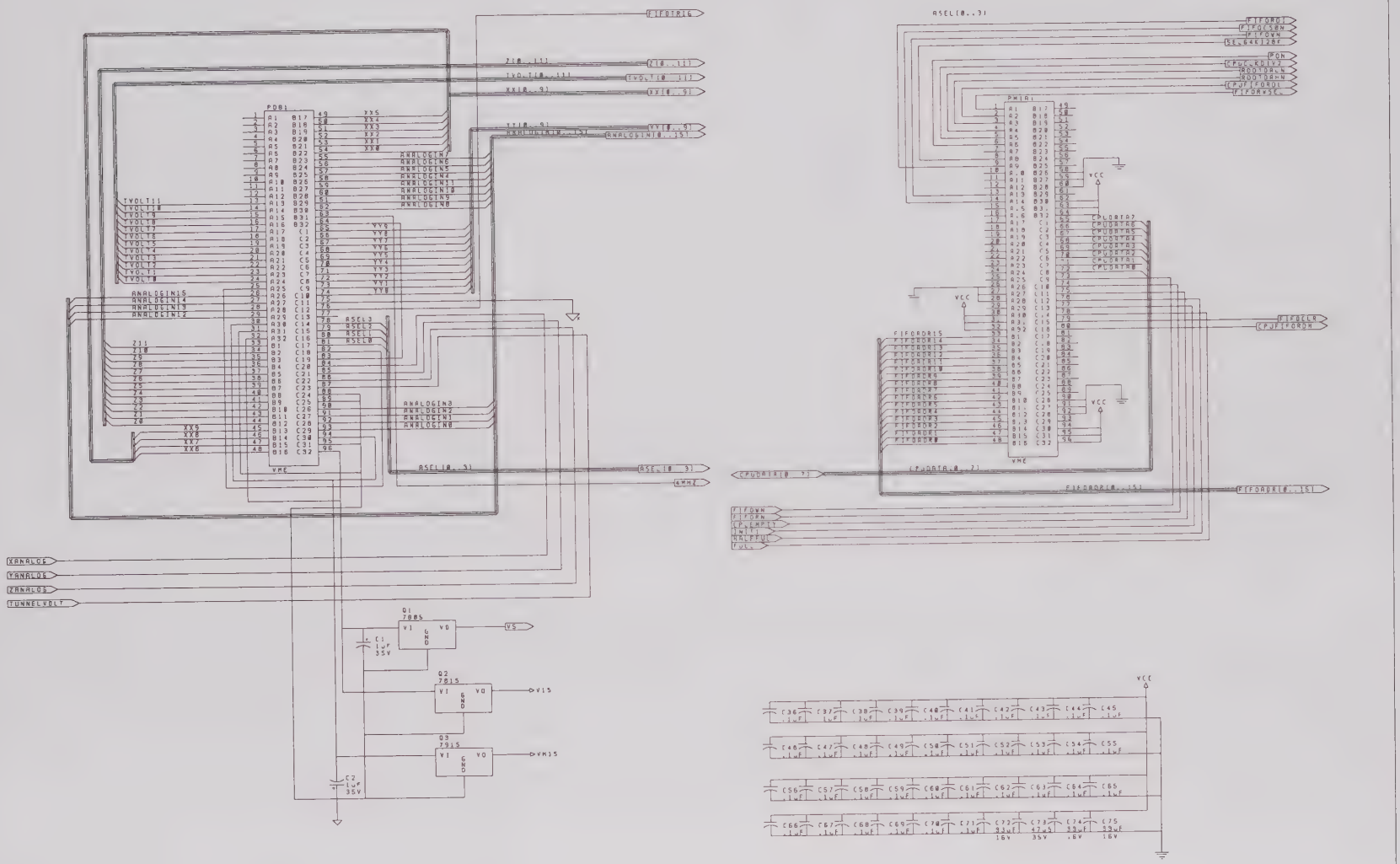
Title
Schematic, Analog / Memory Board

Size	Document Number	REV
A	SK01047	C

Date: June 10, 1991 Sheet 1 of 6



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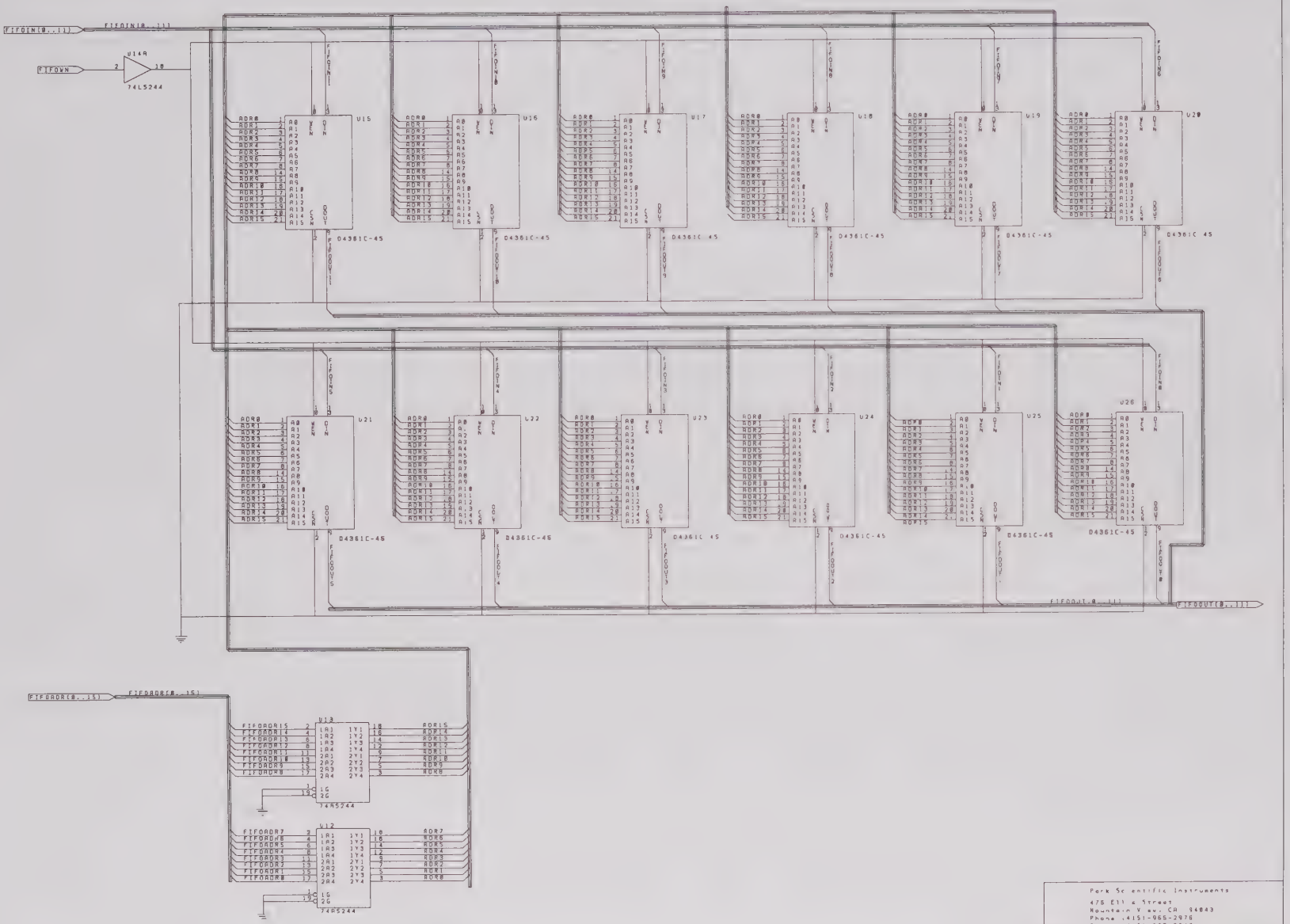
Fax (415)-965-2946	
Title	VME Connectors & Bypass Caps
Size C	Document Number SK01040
REV C	
Date: May 10, 1990	Sheet 2 of 6



Perk Scientific Instruments
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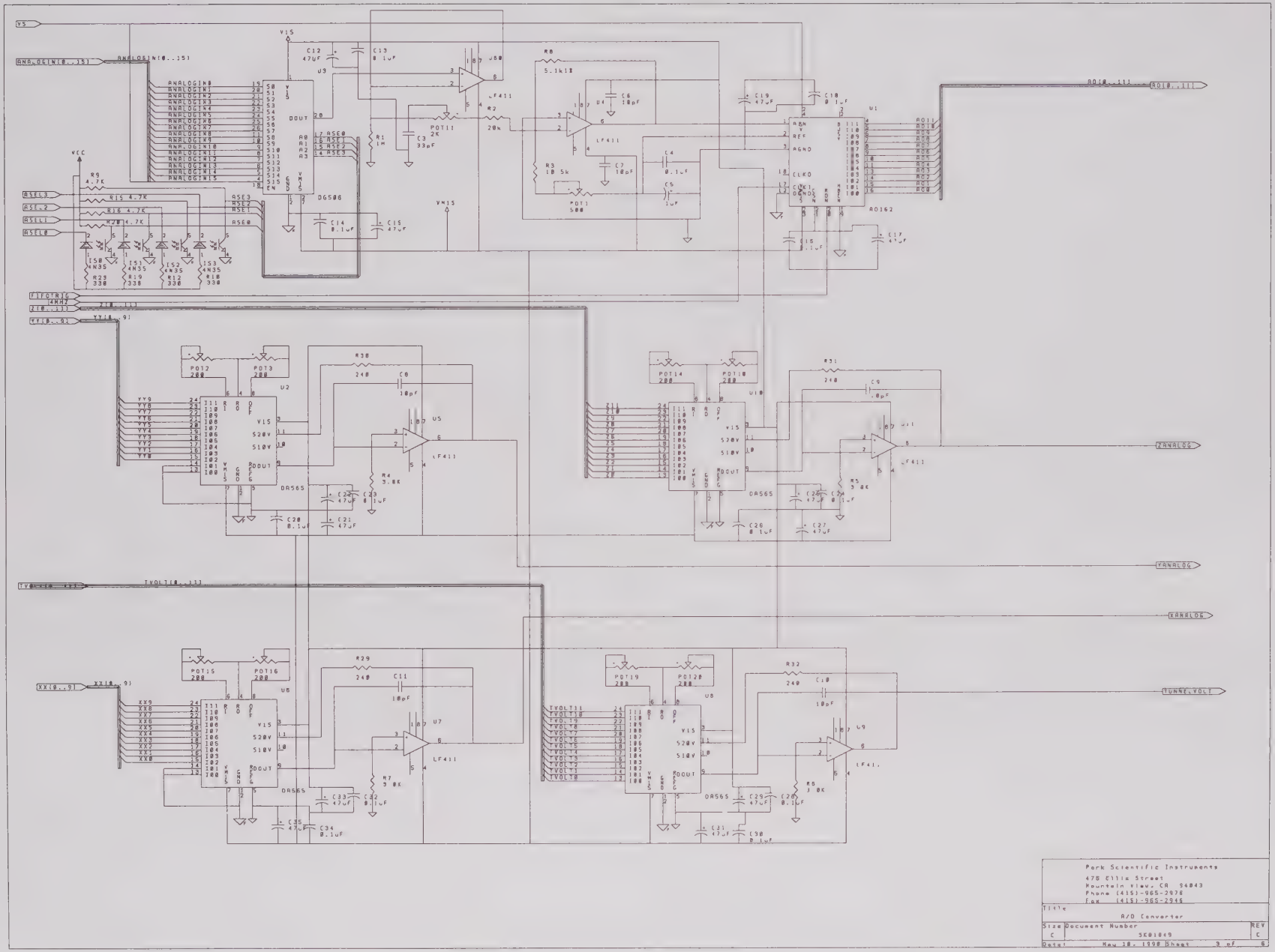
Title: FIFO Memory

Size	Document Number	REV
C	SK0185B	C

Date: Nov 18, 1998 Sheet 4 of 6


Park Scientific Instruments
478 Ellis Street
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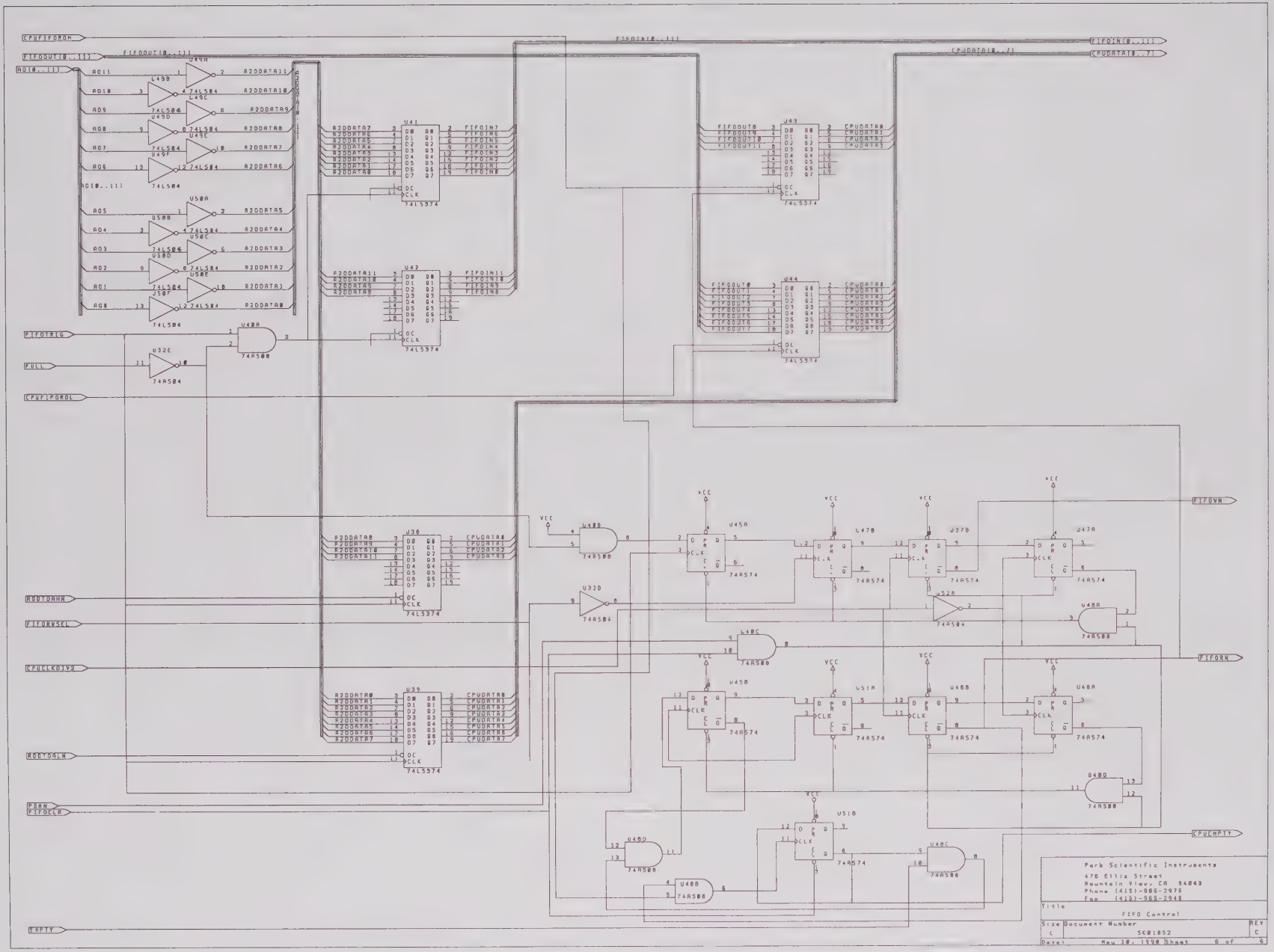
Fax (415)-965-2946
Title
A/D Converter
Size
C
Document Number
SK01049
REV
C
Date: May 18, 1998 Sheet 3 of 6


CPUFIFORDH
FIFOOUT[0..11]
AD[0..11]
FIFOIN[0..11]
CPUDATA[0..7]
74LS04
74LS374
74AS00
74AS04
74AS74
FIFOTRIG
FULL
CPUFIFORDL
R2DDATR[0..11]
FIFOIN[0..11]
R2DDATR[0..7]
CPUDATA[0..7]
RDDTDHN
FIFORVSEL
CPUCLKDIV2
RDDTDLN
PDNN
FIFOCLR
EMPTY
FIFOVN
FIFORN
CPUEMPTY
VCC
Park Scientific Instruments
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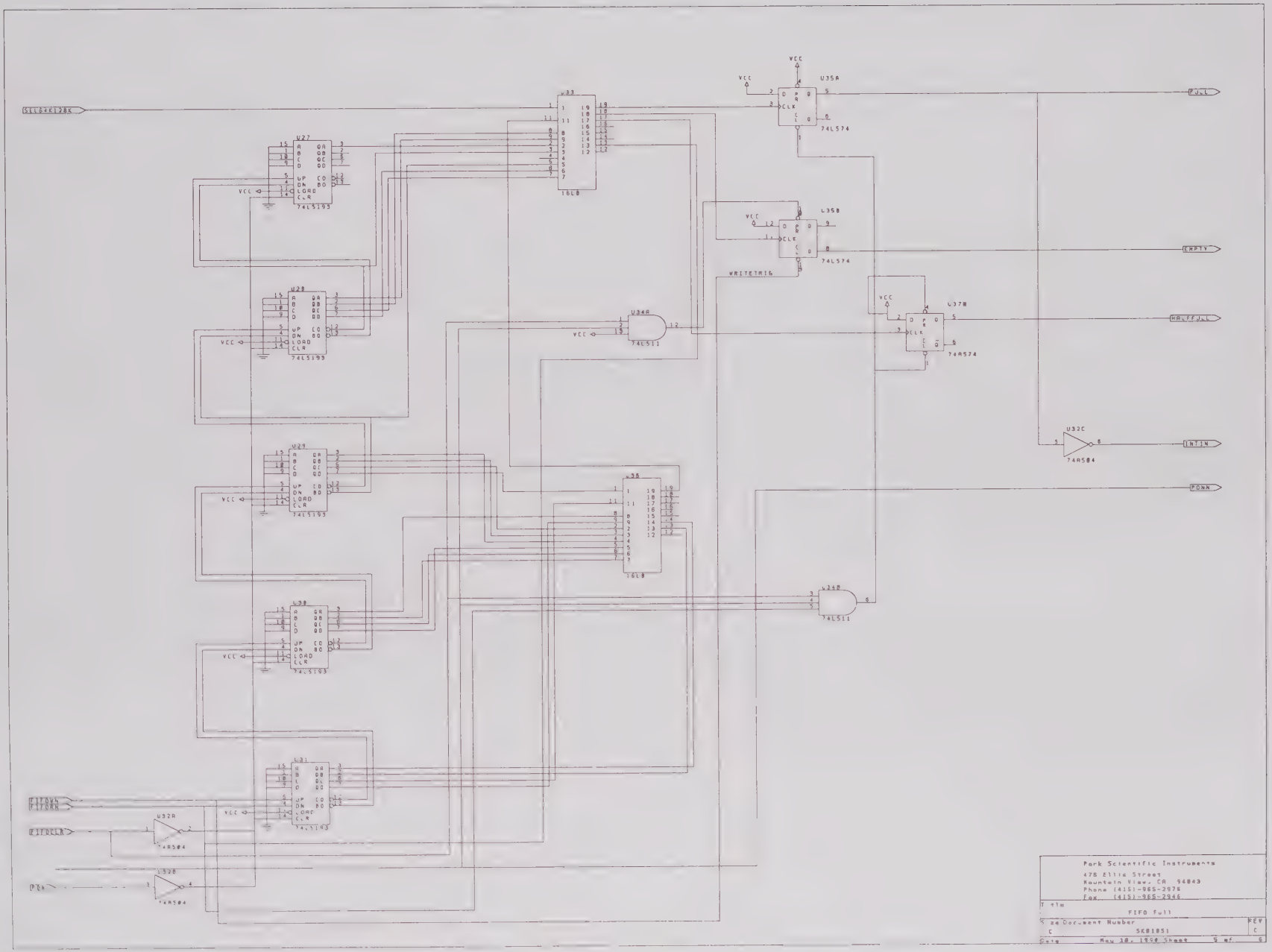
Phone (415)-965-2978
Fax (415)-965-2946
Title
FIFO Control
Size C
Document Number SK01052
REV C
Date: May 18, 1990 Sheet 6 of 6


Park Scientific Instruments
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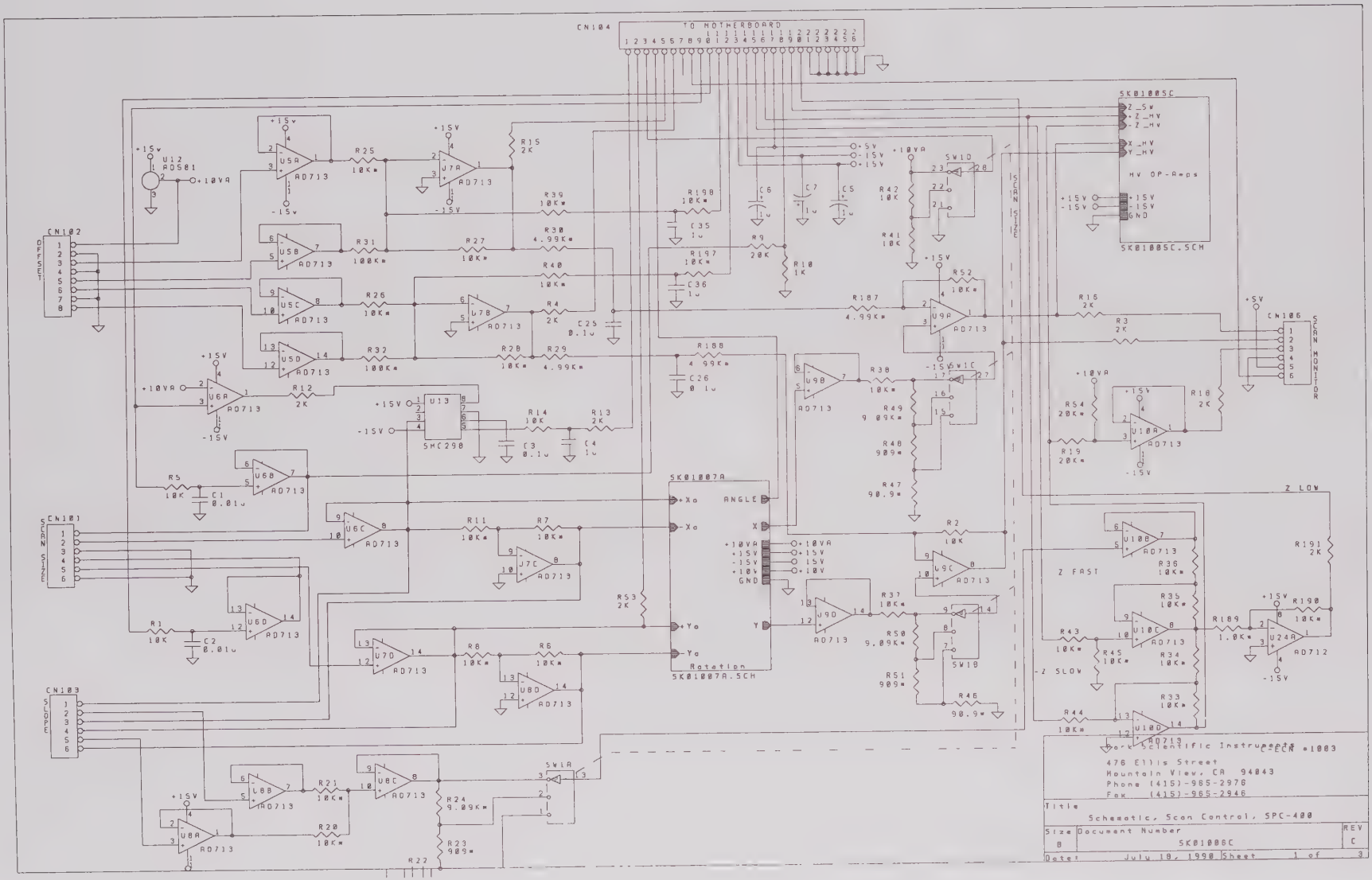
Phone (415)-965-2976
Fax (415)-965-2946
FIFO Full
Document Number
5K81851
Rev
C
Date: May 10, 1990 Sheet 5 of 6


CN104
TO MOTHERBOARD
SK01005C
Z_SW
Z_HV
Z_HV
X_HV
Y_HV
HV OP-Amps
+15V
-15V
GND
SK01005C.SCH
CN102
OFFSET
CN101
SCAN SIZE
CN103
SLOPE
CN105
SCAN MONITOR
SCAN SIZE
+10VA
+15V
-15V
+5V
AD713
AD712
SMC298
SK01007A
ANGLE
Xo
Yo
Rotation
SK01007A.SCH
Z FAST
Z SLOW
Z LOW
SW1A
SW1B
SW1C
SW1D
Stanford Scientific Instruments
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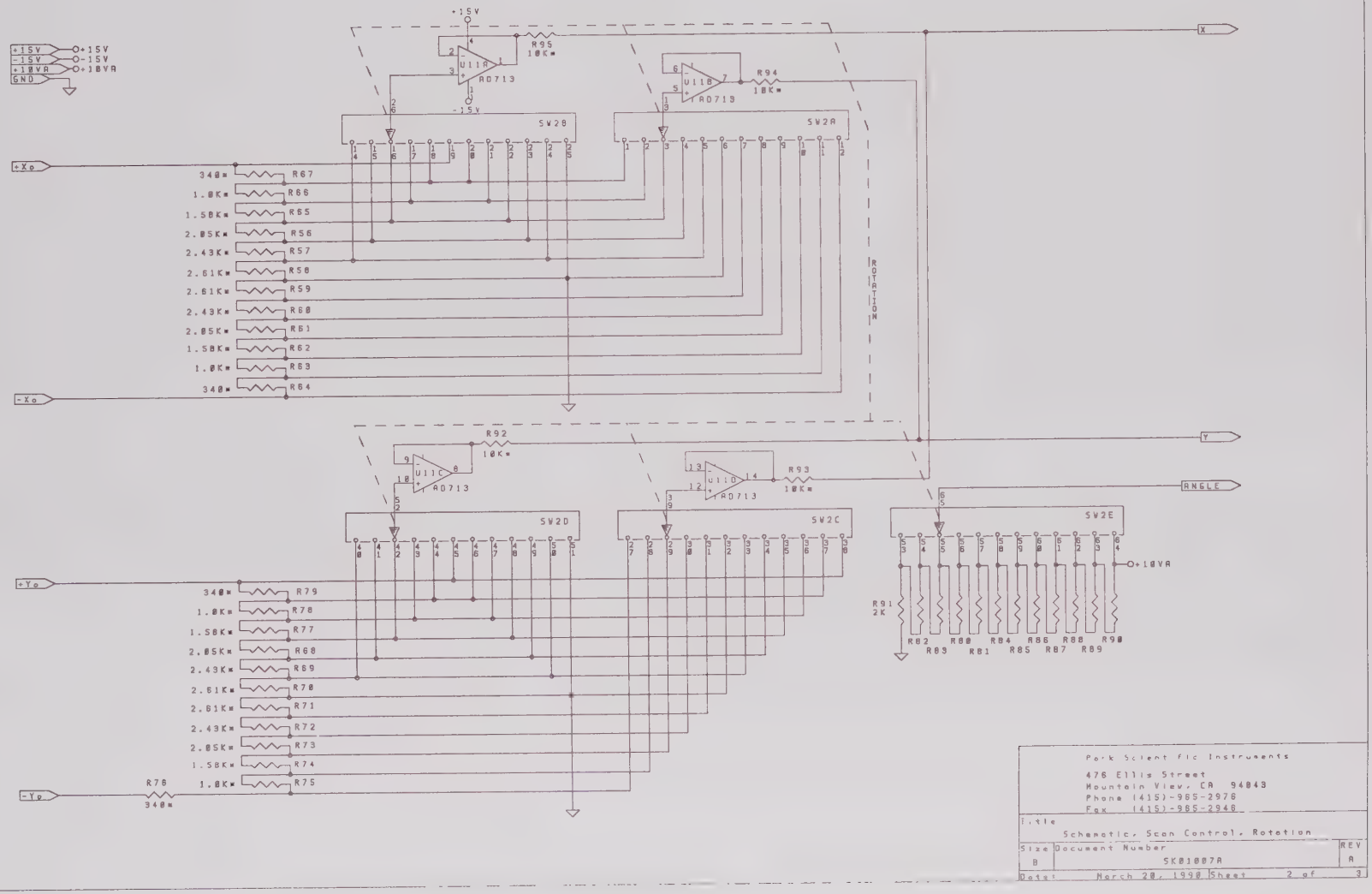
Title
Schematic, Scan Control, SPC-400
Size
B
Document Number
SK01008C
REV
C
Date: July 10, 1990 Sheet 1 of 3



Park Scientific Instruments
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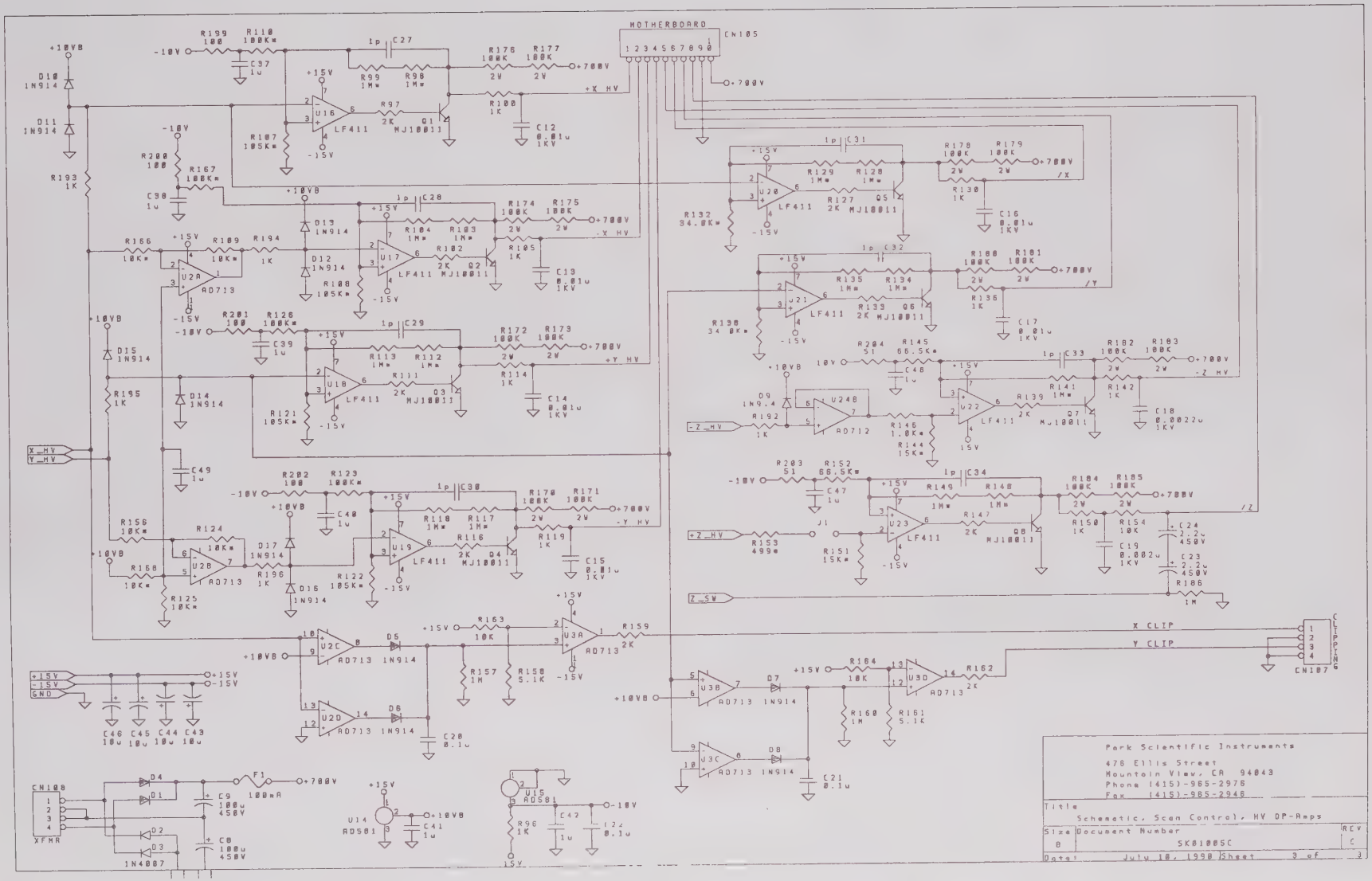
Title: Schematic, Scan Control, Rotation		
Size: B	Document Number: SK01007A	REV: A
Date: March 20, 1990	Sheet 2 of 3	


MOTHERBOARD
CN105
+700V
-700V
+X HV
-X HV
+Y HV
-Y HV
+Z HV
-Z HV
X_HV
Y_HV
Z_SW
X CLIP
Y CLIP
CN107
CN108
XFMR
+15V
-15V
+10VB
-10V
GND
LF411
AD713
AD712
AD581
1N914
1N4007
MJ10011
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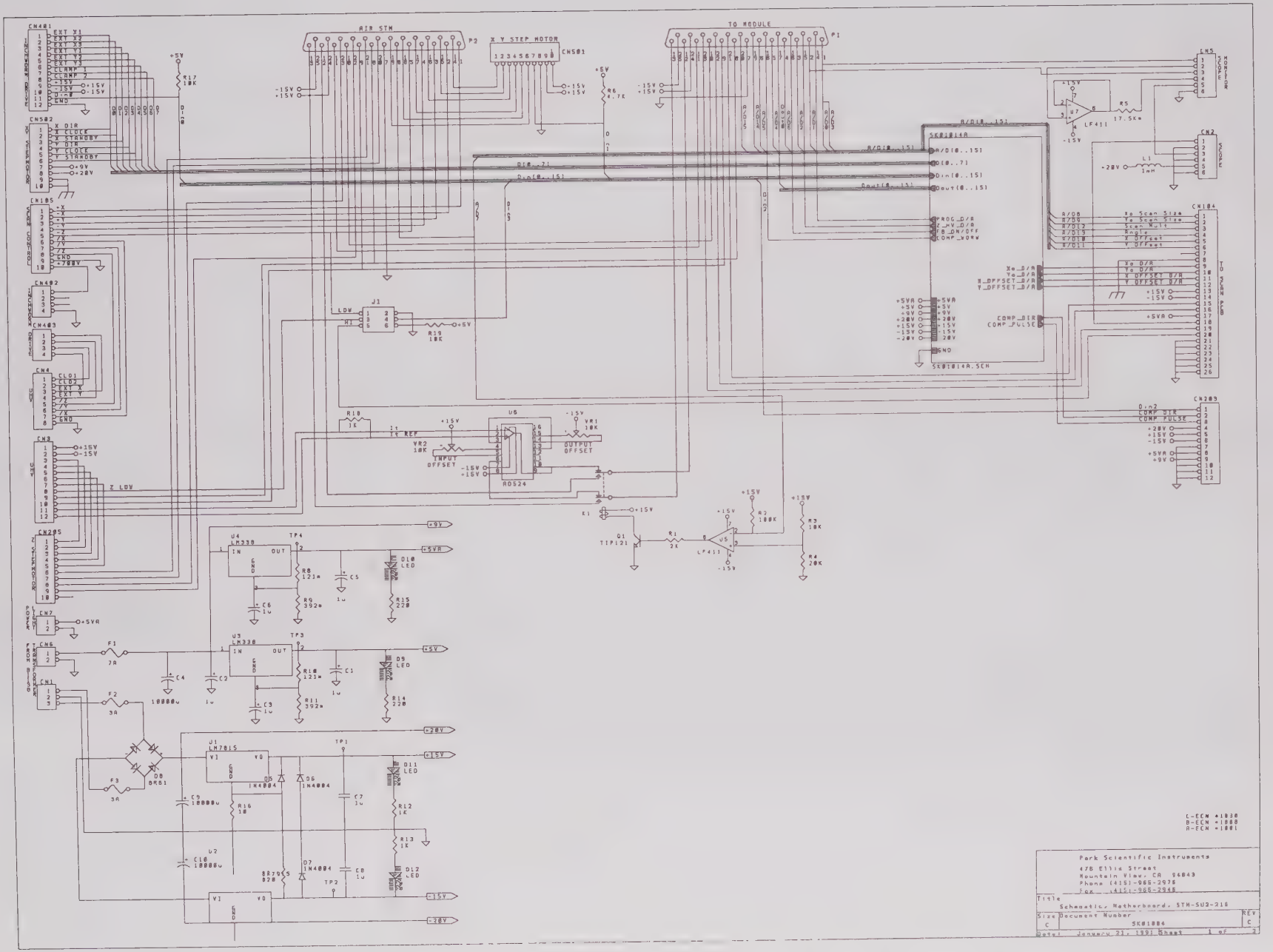
Fax (415)-965-2946
Title
Schematic, Scan Control, HV OP-Amps
Size B
Document Number SK0100SC
REV C
Date: July 10, 1990 Sheet 3 of 3


AIR STM
TO MODULE
X Y STEP MOTOR
CN501
P2
P1
CN481
CN502
CN105
CN402
CN403
CN4
CN3
CN205
CN7
CN6
CN1
CN5
CN2
CN104
CN203
SK0804A
SK0804A.SCH
A/D[8..15]
A/D[0..7]
Din[0..15]
Dout[8..15]
PROG_D/A
Z_HV_D/A
FB_ON/OFF
COMP_NORM
Xo_D/A
Yo_D/A
X_OFFSET_D/A
Y_OFFSET_D/A
COMP_DIR
COMP_PULSE
Xo Scan Size
Yo Scan Size
Scan Mult
Angle
X Offset
Y Offset
LDW
Z LDW
U1 LM7815
U2 LM7915
U3 LM338
U4 LM338
U5 LF411
U6 AD524
U7 LF411
Q1 TIP121
D1 1N4004
D2 1N4004
D3 1N4004
D4 1N4004
D5 1N4004
D6 1N4004
D7 1N4004
D8 KBU1
D9 LED
D10 LED
D11 LED
D12 LED
D13 LED
D14 LED
D15 LED
R1 2K
R2 100K
R3 10K
R4 20K
R5 17.5K
R6 4.7K
R8 121R
R9 392R
R10 121R
R11 392R
R12 1K
R13 1K
R14 220
R15 220
R16 10
R17 10K
R18 1K
R19 10K
VR1 10K
VR2 10K
F1 7A
F2 3A
F3 3A
L1 1mH
K1
TP1
TP2
TP3
TP4
OUTPUT OFFSET
INPUT OFFSET
Park Scientific Instruments
476 Ellis Street
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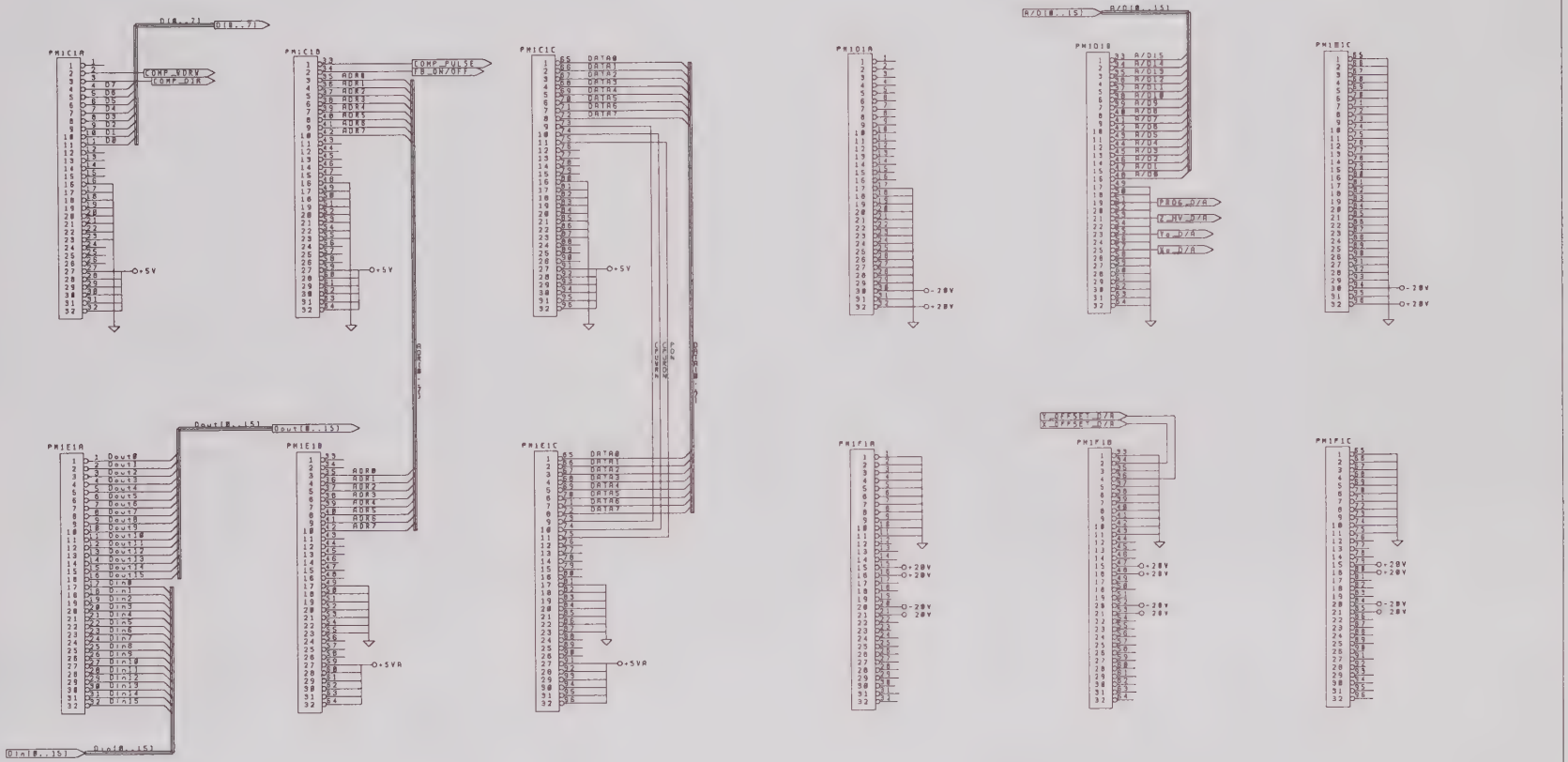
Fax (415)-965-2948
Title
Schematic Motherboard STM-SU2-218
Size Document Number
SK0804
Rev C
Date: January 21, 1991 Sheet 1 of 2



Park Scientific Instruments
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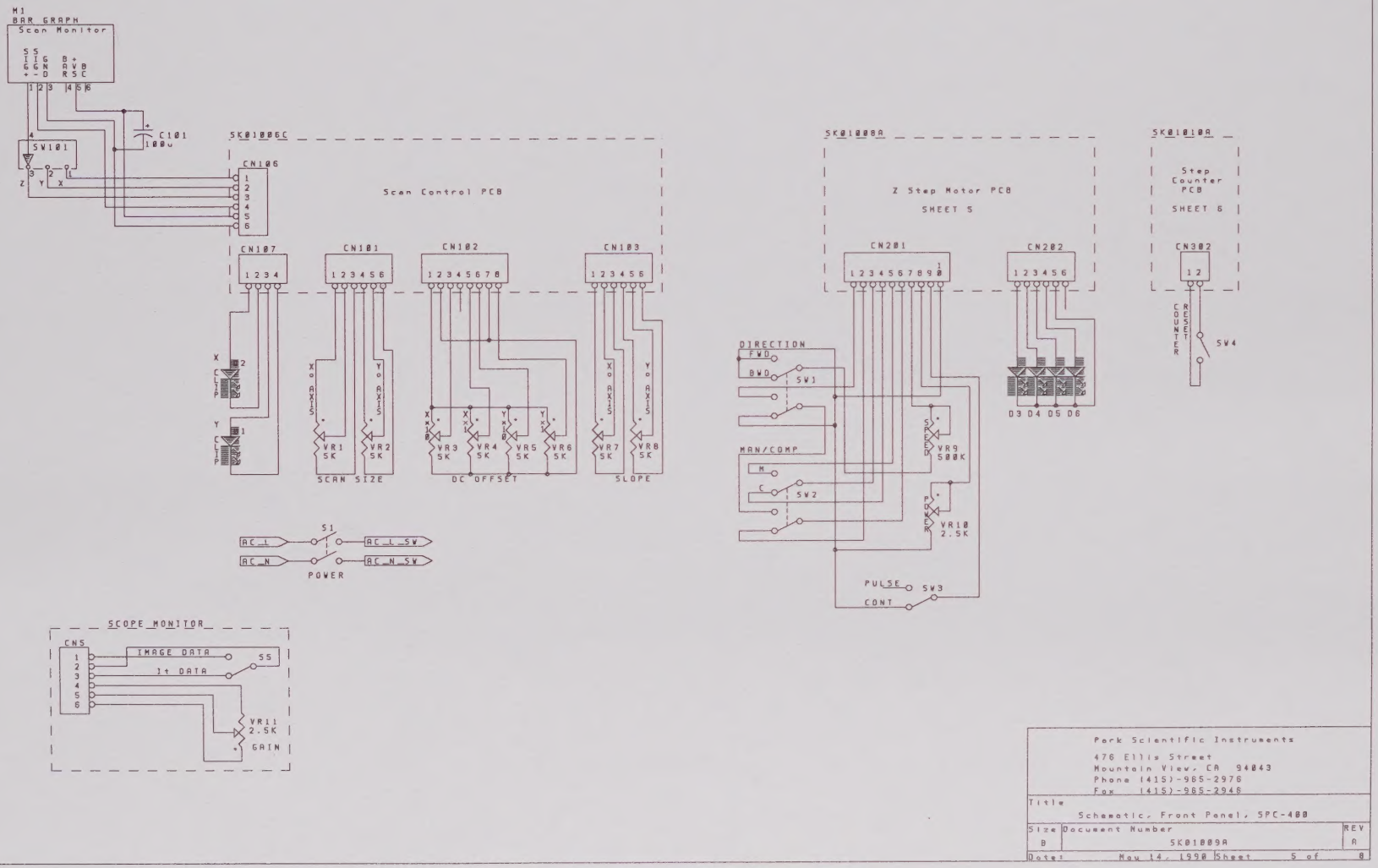
Fax (415)-965-2945

Title: Schematic, Motherboard, VME Connectors

Size	Document Number	REV
C	SK01014A	A

Date: May 11, 1990 Sheet 2 of 2



Park Scientific Instruments	
476 Ellis Street Mountain View, CA 94043 Phone (415)-965-2976 Fax (415)-965-2946	
Title	Schematic, Front Panel, SPC-480
Size: B	Document Number: 5K01009A
REV: A	
Date: May 14, 1990	Sheet 5 of 8

MP MASTER
MA32966